MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 103 No. 2

1943 APRIL 9

ANNUAL GENERAL MEETING

Professor S. Chapman, President, in the Chair

The Minutes of the preceding Annual General Meeting were read and confirmed.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Albert Edward Carter, 30 Primrose Hill, Bath, Somerset (proposed by D. H. Sadler);
Ernest Edwin Perrin, M.Sc., 38 Lime Tree Grove, Shirley, Croydon, Surrey (proposed by P. J. Melotte);
Richard Griffith Quirk, A.I.N.A., 23 Eden Quay, Dublin (proposed by H. Freyne); and
George Cecil Losh Saul, R.N.R. (Retd.), F.R.E.S., A.I.N.A., 12 Manor Road, Beckenham, Kent (proposed by G. W. Wakeford).

The election by the Council of the following Fellows was duly confirmed:—

Herbert Coates, M.A., Mill Hill School, St. Bees, Cumberland;
Albert William Francis Hallam, 44 Parklands Road, Streatham Park, London, S.W. 16;
William S. Mason, 62 Grafton Road, Auckland, New Zealand;
Douglas Walter Noble Stibbs, New England University College, Armidale, New South Wales, Australia;
Oliver Rowland Walkey, Stanford Bishop Vicarage, Bringsty, Worcester; and
John Douglas Ford Williams, B.Sc., 116 Birmingham Road, Allesley, Coventry, Warwickshire.

The Address on the award of the Gold Medal was delivered by the President (see p. 116), after which the Gold Medal was presented to Dr. H. Spencer Jones, Astronomer Royal, to whom it had been awarded for his determination of the Solar Parallax.

The President then delivered his Address on "Magnetism in the Sun's Atmosphere" (see p. 117).

After the delivery of the President's Address, visitors were requested to withdraw and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 63).

The Treasurer referred to one or two items appearing in the accounts for the year 1942.

A vote of thanks to the Auditors of the Treasurer's Accounts for 1942 was proposed and carried unanimously.

A vote of thanks to the Westminster Bank, Ltd., for their gratuitous services to the Society was proposed and carried unanimously.

The following additional Bye-law, 26B, which was proposed by the Council, was put to the Meeting and carried:—

> "The provisions of Bye-law 26A may be applied, at the discretion of Council, to any Fellow of the Society, who, owing to war conditions, is unable to continue to pay his or her contributions."

The Secretaries moved the following resolution on behalf of Council:—

> "*Resolved*: That certain of the books, duplicated in the Society's Library, left to the Society by the late A. Stanley Williams, Esq., and presented by the widow of the late W. G. Bell, Esq., be presented to the British Astronomical Association and the Editors of *The Observatory*."

This resolution was carried.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 131.

The President read a letter he had received from the Russian Academy of Sciences expressing the good wishes of Russian scientists and a letter from Dr. Neujmin which contained an ephemeris of Comet Neujmin II.

The Secretary read extracts from the Annual Report of the Council.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Addresses.

The thanks of the Society were given to the retiring President (Professor Chapman), Vice-President (Dr. Spencer Jones), Secretary (Dr. Thackeray), and other retiring members of Council.

The thanks of the Meeting were given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND TWENTY-THIRD ANNUAL GENERAL MEETING OF THE SOCIETY

1. *General.*—The calendar year 1942, to which the following report refers, has seen a return to a stabilized programme of meetings, both of Council and of the Society, and, generally, an approach to more normal conditions. With the majority of professional astronomers engaged on war work, and the virtual cessation of astronomical research, a serious decline in the number of papers submitted for publication and available for reading at meetings was inevitable; it was possible, however, to publish six numbers of *Monthly Notices* and to hold five meetings devoted to the reading of original papers. At the meeting of October 9, which was devoted to a celebration of the Anniversaries of Galileo, Newton and Halley, a large number of visitors, representing scientific Societies and other bodies, were present. The stabilization referred to therefore coincides with a revival of interest in the Society's activities; in no small measure this is due to Council's decision to move the executive offices of the Society back to Burlington House, resulting in an increased availability of the library. The number of visitors to the library is now equal to that in pre-war years.

During the year an arrangement was entered into with the British Astronomical Association, by which the Association is provided with accommodation for its library and has the use of the Meeting and Council Rooms for its meetings. The Association moved its library in August and has since used the Society's premises for meetings. In the words of the President, in announcing this arrangement at the Annual General Meeting, "it is confidently hoped that this arrangement will be beneficial to the interests of British Astronomy, which both the Society and the Association have served so well in their different ways." Experience so far obtained shows that the arrangement is in no way detrimental to the interests and convenience of Fellows, while it is proving most satisfactory to Members of the Association.

2. *Membership.*—The Council record with regret the death of two Associates (Heber Doust Curtis and Hermann Albert Kobold), and of thirteen Fellows, as under; their deaths occurred in 1942 except where an earlier year is indicated. Obituary Notices are given on pp. 64–76.

Walter George Bell
*William Bowyer
James Ruthven Brown
*George Douglas Buchanan (1941)
*Andrew Russell Forsyth
John H. Hindle
*Joseph Larmor
*A. W. Tindall Lucas (1941)
George Tyrrell McCaw
Arthur Maitland Peckham
*Theodore Evelyn Reece Phillips
William John Roberts
*Francis James Wardale

* Life Fellow.

A table giving detailed statistics of the membership of the Society on 1943 January 1 is given on p. 51. In view of the uncertainty arising from the corrections to the table for previous years, a complete check of the Fellowship has been made and confirmed by the professional auditors.

3. *Meetings during* 1942.—The Annual General Meeting was held in April, and there were six Ordinary Meetings, the first one in March and then monthly from May to

October with the exception of August. The October meeting was devoted to the celebration of the anniversaries of Galileo, Newton and Halley. Meetings generally began at $16^h\ 30^m$ as in 1941, and were timed to end at 18^h. Attendances were larger than in 1941, but not up to peace-time averages. The average number of Fellows attending the 1942 meetings was 49, as compared with 39 in 1941.

4. *Geophysical Activities.*—A Geophysical Discussion on "The Figure of the Earth" was held in August when the attendance was equal to pre-war numbers. One *Geophysical Supplement* was published (Vol. 5, No. 2), and three geophysical papers since received will be published in a forthcoming number.

5. *George Darwin Lecture.*—At its meeting in March, Council provisionally invited Dr. Theodore Dunham, Jr. to give the George Darwin Lecture in 1942. At that time there appeared to be good prospects of Dr. Dunham being able to deliver the Lecture, but it subsequently proved impossible for him to visit this country. Accordingly, as in 1940 and 1941, no George Darwin Lecture was given.

6. *Awards.*—No Gold Medal was awarded in 1942.

7. *Finance.*—In the Treasurer's accounts two fresh items appear—(1) a Bonus payment of £116, 18s. to the former Assistant Secretary, Miss K. Williams, and (2) a payment of £50 which is the first annual contribution to a Staff Pension Fund, to be utilised in any way the Council may decide. The War Damage Insurance contribution for the year is £122, 10s., which, however, is not strictly comparable with the same item for 1941 as the latter was retrospective to the beginning of the War. The accounts of the Society have been examined by a firm of professional accountants as last year, and have been certified correct.

8. *Publications.*—During 1942 the Society published *Monthly Notices*, Vol. 102, and *Geophysical Supplement*, Vol. 5, No. 2.

The shortage of papers, referred to in section 1, has made it necessary still further to restrict the number of separate numbers of *Monthly Notices*; Vol. 102 consists of six numbers only, not associated with particular monthly meetings. The total number of pages is 277 (including 90 pages for the Annual Report of Council), as compared with 391 in 1941. Paper restriction has not fallen hardly on the Society because of the reduction in the number of communications received.

9. *Exchange of Publications.*—The American Committee for the Continued Distribution of Astronomical Literature has assisted the Society by sending copies of some American publications whose distribution had been interrupted, and also by distributing copies of *Monthly Astronomical News-Letter* which gives summaries of articles published in America and elsewhere and general surveys of progress in astronomical research. The Committee also arranged for the loan from Professor Struve of his personal copy of the *Strömgren Festschrift* and of a copy of the *Astronomischer Jahresbericht* 1939. Through the services of the British Council it has been possible to resume exchange with two Observatories in Sweden and to receive publications from that country. A few publications have been received from Russia, and the Society's publications are being sent there regularly. A stock of publications is being reserved for distribution after the War to those Observatories and Institutions with which communication is at present impossible.

10. *The Library.*—The use of the library has increased considerably with the return of the office to London. In 1938, 349 books were borrowed by 78 different borrowers; in 1940, 98 books by 37 different borrowers, and in 1941, 98 books by 38 different

borrowers, whilst in 1942 (4 months with the office at Oxford and 8 months in London) 252 books were borrowed by 59 different borrowers.

The more rare and valuable books are still in Oxford.

Two lists of *Additions to the Library* (other than by exchange) were issued during 1942.

A list of those who have presented gifts to the library other than by exchange is given on p. 63.

The following special gifts were made to the library:—

(1) Pigott MSS., by Major George Anne;
(2) Books belonging to the late W. G. Bell, by his widow;
(3) Photo-lithograph of Halley's Tidal Chart of the English Channel, by the Royal Geographical Society.

On the return of the Society's office to Burlington House it was possible to consider the disposal of the books bequeathed to the Society in 1938 by the late A. Stanley Williams. Proposals regarding the disposal of these books together with those of the late W. G. Bell will be submitted for consideration by the Society.

Council much regret to report that, between the date (1939) of receipt of the Stanley Williams books and 1942 October, forty-one of these books had been removed from the Society's premises.

No binding has been done during 1942.

11. *The Society's Office and Staff.*—The executive Offices of the Society were moved back from the University Observatory, Oxford, to Burlington House during the year; the Assistant Secretary came back into residence on May 1 and the porter and his wife on April 28.

The Assistant Secretary, Miss K. Williams, L.R.A.M., retired through ill-health on July 31, after having served the Society as Assistant Secretary for 19½ years. During the War she had carried out the office duties under difficult conditions with only occasional clerical assistance. The Society is indebted to her for her long and devoted service. In view of the reasons for her early retirement, Council made up the surrender value of the pension policy, held on her behalf, to £1000.

The Society has been fortunate in being able to recall Miss E. Wadsworth, M.A., to serve as Assistant Secretary; Miss Wadsworth was formerly the Clerk, but had been on leave from the service of the Society during the War.

The resignation of Miss Williams, part of whose emoluments consisted of the flat in Burlington House, gave Council the opportunity of making the post of Assistant Secretary non-resident; it had long been felt that such residence was inappropriate in Burlington House. The porter and his wife, acting as caretakers, continue to be provided with accommodation in the basement.

12. *The Society's Premises.*—See section 15.

13. *The Society's Movable Property and Instruments.*—During the year the opportunity has been taken further to disperse stocks of publications; in other respects the Society's valuable property continues to be stored either in the strong room at Burlington House or at the University Observatory, Oxford. The death of the Rev. T. E. R. Phillips raised the question of the storage of the telescopes on loan to him from the Society, and erected at his observatory at Headley. The Society, in conjunction with the British Astronomical Association, has taken over the rental of the Observatory paddock and the insurance of the instruments which remain *in situ*. Their ultimate disposal will be deferred until after the War.

A celestial globe and a six-inch object-glass used by the late W. F. Denning have been presented to the Society by his sister, Mrs. Willett.

The Council decided to purchase if possible from Fellows copies of the Society's slides and thus to accumulate a collection of slides for hiring purposes to Fellows; such stock of prints as the Society possesses is still for sale, but the stock cannot be replaced.

14. *The Observatory.*—In accordance with the agreement (section 16, Annual Report for 1941) with the Editors of *The Observatory*, Fellows have received the six 1942 issues of the magazine.

15. *The British Astronomical Association.*—As announced by the President at the Annual General Meeting in April (see *M.N.*, vol. **102**, p. 43) the British Astronomical Association accepted the Society's invitation to share the Society's premises in Burlington House. Two second floor rooms, previously part of the Assistant Secretary's flat, have been put at the Association's disposal for the accommodation of its library. The agreement also allows for the use of the Meeting Room and Council Room. The arrangement is in the first instance for the duration of the War or a period of two years whichever is the longer.

The Association moved into Burlington House on August 31 and the first meeting of its Members took place on September 30; two Meetings and three Council meetings were held during the year. The Association's library is open to Members from 13^h to 16^h on Wednesdays.

16. *The London Mathematical Society.*—During 1942 the London Mathematical Society held four meetings at the Society's rooms.

17. *Proceedings of Observatories.*—Reports from the Directors of Observatories are included in this issue. In inviting Directors to contribute reports, Council requested that their reports should be as concise as possible and that they should be restricted primarily to general descriptions of programmes of astronomical work; the absence of reports from particular observatories does not, however, indicate that no astronomical work is being done.

18. *Reports on the Progress of Astronomy.*—This issue of *Monthly Notices* contains, as in past years, several reports on astronomical progress. A report from Kodaikanal Observatory on Solar Prominences during 1941, received too late for publication last year, has been included.

19. *Lists of Exchanges, Instruments, etc.*—These have been omitted from the Report. No celestial photographs have been added to the Society's collection during the year.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Fellows			Associates	Total
			Compounders	Annual Subscribers	Non-active Fellows		
1941 December 31	1	5	177	583	59	48	873
Corrections to figures for 1941 December 31	...	...	+1	+ 2	...	...	...
	1	5	178	585	59	48	876
Since elected	...	...	+1	+17	...	+2	...
Deceased, 1942	...	...	−5	− 6	...	−2	...
Deceased 1941, deaths not notified	...	...	−2	...	...	...	...
Resigned...	...	...	...	− 1	...	...	...
Since compounded	...	...	+3	− 3	...	...	...
Transferred to Suspense Account in 1942:							
(*a*) Subns. unobtainable under war conditions	...	...	...	−24	+24	...	...
(*b*) On Active Service (Bye-law 26A)	...	...	...	− 5	+ 5	...	...
Transferred from Suspense Account in 1942	...	...	...	+ 2	− 2	...	...
1943 January 1	1	5	175	565	86	48	880 *

(* As far as can be ascertained under present circumstances.)

(Nine Associates are also Fellows, and are therefore counted twice in the above table.)

RECEIVED

	£ s. d.	£ s. d.
Balances, 1942 January 1:—		
In hand of Assistant Secretary, on Petty Cash Account	3 18 4	
At Westminster Bank, on Current Account	506 9 9	
At Westminster Bank, on "B" Account:—		
A. S. Williams Bequest	52 10 0	
At Westminster Bank, on "C" Account:—		
Trust Funds £522 14 11		
Sales of Duplicate Books Fund 63 9 9		
Goodridge Bequest 6 17 4		
	593 2 0	
At Post Office Savings Bank	1029 6 10	
At London Savings Bank—Ordinary Dept. (including £250 A. S. Williams Bequest) £1021 16 0		
Special Investment Department 513 6 9		
	1535 2 9	
		3720 9 3
Dividends on Investments	580 6 0	
Interest on Savings Banks Deposits	65 7 2	
Income Tax refunded: 1941 April–December £177 6 8		
1942 January–April 108 9 0		
	285 15 8	
Sales of Publications:—		
For 1942 £166 18 5		
Due in 1941 2 0 4		
1943 in advance 22 4 3		
	191 3 0	
Reprints:—		
For 1942 £7 18 11		
Due in 1941 3 1 6		
	11 0 5	
Sales of Photographs and Hire of Slides	7 14 9	
Miscellaneous Receipts:—		
London Mathematical Society £7 10 0		
Assistant Secretary, Pension Contribution 8 0 0		
Excess on Subscriptions 0 12 3		
Postages repaid 1 7 8		
Proceeds of Pension Policy, former Assistant Secretary 883 2 0		
	900 11 11	
		2041 18 11
Received on Account of Subscriptions:—		
465 Annual Contributions, 1942	976 10 0	
4 Institutional Membership Fees, 1942	8 8 0	
14 Annual Contributions, 1943, in advance	29 8 0	
1 ditto, 1944, in advance	2 2 0	
17 Admission Fees, 1942	35 14 0	
16 First Contributions, 1942	27 6 0	
Arrears paid off:—		
3 for 1940 £6 6 0		
33½ for 1941 70 7 0		
1 Admission Fee and First Contribution, 1941 3 3 0		
	79 16 0	
		1159 4 0
Compositions:—		
1 Initial	31 10 0	
3 Reduced	35 14 0	
		67 4 0
"C" Account:—		
Dividends on Investments	158 12 2	
Income Tax refunded: 1941 April–December £35 7 2		
1942 January–April 4 11 0		
	39 18 2	
Interest on Post Office Savings Bank Account	5 4 2	
		203 14 6
		£7192 11 1

ASTRONOMICAL SOCIETY, FROM 1942 JANUARY 1 TO DECEMBER 31

Account

PAID

	£ s. d.	£ s. d.	£ s. d.
Assistant Secretaries: Salaries	£275 18 0		
Inland Revenue: Income Tax on ditto	49 19 10		
		325 17 10	
Former Assistant Secretary: Rent, etc.	... ...	40 10 0	
Assistant Secretary: Pension Premium	... ...	24 0 0	
Health and Unemployment Insurance		3 0 6	
Porter and Wife: Wages and Cleaning	... ...	192 2 6	
Pension Contribution	... ...	13 0 0	
Health and Unemployment Insurance		6 14 6	
			605 5 4
Former Assistant Secretary: Commuted Pension and Bonus		... ...	1000 0 0
Insurance (general), Water Rate and Telephone		47 2 6	
War Damage Insurance, paid up to 1943 March 31		157 10 0	
			204 12 6
Postage and Packing:—			
Monthly Notices, etc.		58 14 4	
Office Postages		50 2 0	
			108 16 4
Printing, etc.:—			
Monthly Notices (Vol. 101, Nos. 7–8; Vol. 102, Nos. 1–5)		596 7 8	
Geophysical Supplements (Vol. 5, No. 2)		39 12 1	
Reprints		42 7 0	
Miscellaneous		13 19 6	
Photo-engraving		35 1 4	
			727 7 7
Headley Observatory:—			
Rent of Observatory Paddock	£2 18 4		
Insurance of Buildings and Instruments on Site	2 11 6		
Camouflage	6 15 0		
Mr. Maskell for care of Site	1 10 0		
		13 14 10	
Less Contribution from British Astronomical Association		1 9 2	
			12 5 8
A.R.P. Expenditure (other than War Damage Insurance)		66 2 1	
Stationery and Office Expenses		33 19 8	
Heating and Lighting		73 6 6	
Accountant's Fee		21 0 0	
Subscription to Committee on Library Co-operation		1 1 0	
Authorised Travelling Expenses		30 17 11	
Clerical Assistance		1 8 0	
Fittings and Repairs	£16 1 8		
House Expenses and Laundry	20 8 1		
Expenses of R.A.S. Meetings and Committees	14 12 6		
Miscellaneous Expenditure	17 10 8		
Bank Charges and Cheque Books	1 15 7		
		70 8 6	
Purchase of Books from Potter Fund		1 11 0	
Block Subscription to *The Observatory*		100 0 0	
			399 14 8
			3058 2 1
Expenditure on Trust Accounts:—			
Turnor and Horrocks Fund (Library)		34 8 1	
Harry Watson Fund (Library)...		11 3 4	
Jackson-Gwilt Fund (Medal and Gift)		25 0 0	
			70 11 5
Purchase of Book from Sales of Duplicate Books Fund		... ...	7 11 3
Balances, 1942 December 31:—			
In hand of Assistant Secretary, on Petty Cash Account		10 9 1	
At Westminster Bank, on Current Account, as per Pass Book	£663 14 10		
Less Cheques not yet presented	18 18 2		
		644 16 8	
At Westminster Bank, on "B" Account (A. S. Williams Bequest)		52 10 0	
At Westminster Bank, on "C" Account:—			
Trust Funds...	£198 19 6		
Sales of Duplicate Books Fund	5 18 6		
Goodridge Bequest	8 11 8		
		213 9 8	
At Post Office Savings Bank:—			
General Fund	£1055 1 4		
"C" Account	505 4 2		
		1560 5 6	
At London Savings Bank:—			
Ordinary Department (including £250 A. S. Williams Bequest)	£1047 6 6		
Special Investment Department	527 8 11		
		1574 15 5	
			4056 6 4
			£7192 11 1

Dr. *General Fund Revenue Account*

	£	s.	d.	£	s.	d.
To Salaries and Wages, including Allowance for Rent, Pension Premiums and National Insurance				597	5	4
,, Insurance, Water Rate and Telephone (after adjusting Reserves)...				42	13	3
,, War Damage Act, 1941, Part II: Premiums to 1942 December 31				122	10	0
,, Printing, etc. (after adjusting Reserves)				727	7	7
,, Posting and Packing (after adjusting Reserves)				107	8	8
,, *General Expenses (after adjusting Reserves):—*						
Stationery and Office Expenses	32	8	11			
Lighting and Heating	79	19	6			
Travelling Expenses	30	17	11			
Block Subscription to *The Observatory*	100	0	0			
Clerical Assistance	1	8	0			
Subscription to Committee on Library Co-operation	1	1	0			
Accountants' Fee	21	0	0			
A.R.P. and Fire Watchers' Expenses	65	12	1			
Sundries	70	8	6			
	402	15	11			
,, Purchase of Books from Potter Fund	1	11	0			
				404	6	11
,, Annual Reserve for Repairs				40	0	0
,, Headley Observatory, Expenses less Refunds				12	3	2
,, Commuted Pension Policy and Bonus paid to former Assistant Secretary	1,000	0	0			
Less Received from Insurance Company	883	2	0			
				116	18	0
,, Staff Pension Fund: Amount set aside for year				50	0	0
				2,220	12	11
,, Net Revenue one year to date transferred to Balance Sheet ...				170	12	0
				£2,391	4	11

One Year to 1942 December 31 — *Cr.*

		£ s. d.	£ s. d.
By *Amounts received from Fellows, viz.:—*			
465 Annual Contributions for 1942	£976 10 0		
4 Institutional Membership Fees for 1942 ...	8 8 0		
3 Arrears for 1940	6 6 0		
33½ Arrears for 1941	70 7 0		
20 Prepayments for 1942	42 0 0		
		1,103 11 0	
Admission Fees	... ...	37 16 0	
First Contributions	... ...	28 7 0	
Composition Fees:—			
Initial Fee	£31 10 0		
Reduced Fees	35 14 0		
	67 4 0		
Less Transferred to Reserve Account ...	67 4 0		
	– – –		
Add Amount brought to Credit for the year	48 6 6		
		48 6 6	
			1,218 0 6
„ Interest and Dividends received (gross)	... ...	867 12 10	
„ Interest on Bank Deposit Accounts received ...	... ...	65 7 2	
			933 0 0
„ Sales of Publications, Photographs and Miscellaneous Receipts for the year	... ...		240 4 5
			£2,391 4 11

Note.—Fellows' 1942 Contributions not received were:—

66 Unobtainable under War conditions ...	£138 12 0
20 Waived under Bye-law 26A	42 0 0
70 Others unpaid at 1942 December 31 ...	147 0 0
1 Admission Fee and First Contribution, ditto	3 3 0
Total for the Year	£330 15 0

This amount has been added to the Suspense Account and is not included in this Revenue Account.

Balance Sheet

LIABILITIES

	£ s. d.	£ s. d.
1 Contribution for 1943, paid in 1941	2 2 0	
14 Contributions for 1943, paid in 1942	29 8 0	
1 Contribution for 1944, paid in 1942	2 2 0	
		33 12 0
Sundry Creditors for Accounts due but not presented		145 3 0
Reserve for Repairs and Maintenance:—		
As at 1941 December 31	40 0 0	
Add Set aside 1942	40 0 0	
		80 0 0
Trust Funds and Goodridge Bequest:—		
Capital as at 1941 December 31	4,582 2 7	
Income Balances at 1942 December 31	662 4 11	
Income Tax on Trust Funds, 1942 April–December, not yet refunded	35 7 2	
		5,279 14 8
Special Fund (Capital) as per contra		1,480 2 2
Sales of Duplicate Books Fund:—		
In hand at 1941 December 31	63 9 9	
Add Interest on Post Office Savings Bank Deposit	0 10 5	
	64 0 2	
Less Book purchased 1942	7 11 3	
		56 8 11
Composition Fees Reserve Fund:—		
As at 1941 December 31	738 5 0	
Received in 1942	67 4 0	
	805 9 0	
Less 6% transferred to Current Revenue	48 6 6	
		757 2 6
Franklin-Adams Charts:—		
As at 1941 December 31		170 7 8
Advance Receipts for Publications, 1943		22 4 3
Credits still in hand from 1939		0 15 10
Staff Pension Fund:—		
Amount set aside in 1942		50 0 0
General Fund:—		
As at 1941 December 31	20,177 14 2	
Less Transferred to Sales of Duplicate Books Fund	63 9 9	
	20,114 4 5	
Add Excess of Revenue over Expenditure, 1942	170 12 0	
		20,284 16 5
		£28,360 7 5

To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY.

We have examined the above Balance Sheet with the Books and Vouchers relating thereto explanations given to us.

We have verified the Securities representing the Investments and have found them to be

1942 *December* 31

ASSETS

	£ s. d.	£ s. d.
Sundry Debtors, 1942		42 5 10
War Damage Act, Part II, Premiums paid in advance		35 0 0
Investments of General Fund, valued as at 1922 December 29 or subsequent cost		17,950 5 6
Investments of Special Fund, valued at cost		1,480 2 2
Investments of Trust Funds and Goodridge Bequest, valued as at 1922 December 29 or subsequent cost		4,582 2 7
Income Tax, 1942 April–December, deducted at source, not yet refunded:—		
General Fund	178 17 10	
Trust Funds	35 7 2	
		214 5 0
Sundry Balances, as per Cash Account		4,056 6 4
		£28,360 7 5

Note.—Fellows' Contributions and 2 Admission Fees unpaid at 1942 December 31 : £668, 17s. This amount represents the total of the Suspense Account and is not included in this Balance Sheet.

and certify it to be correctly drawn up therefrom and in accordance with the information and in order.

SUFFOLK HOUSE,
5 LAURENCE POUNTNEY HILL, LONDON, E.C. 4,
1943 *January* 23.

SHARP, PARSONS & CO.,
Chartered Accountants.

INVESTMENTS

As at 1942 December 31

General Fund

£2000 Swansea Corporation 3½ per cent. Stock.
£2287, 6*s.* 9*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£5125 London, Midland and Scottish Railway 4 per cent. Debenture Stock.*
£750 London, Midland and Scottish Railway 4 per cent. Preference Stock.*
£2400 Gas Light and Coke Co. 3 per cent. Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3 per cent. Debenture Stock.*
£496 Consolidated 4 per cent. Stock, 1967.
£500 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent. Redeemable Stock, 1952–72.
£1000 Central Electricity Board 4½ per cent. Stock, 1957–82.*
£700 Birmingham Corporation 3 per cent. Inscribed Stock, 1947.
£1807, 9*s.* 0*d.* War Loan 3½ per cent. Inscribed Stock.
£500 New South Wales 4 per cent. Stock, 1942–62.*
£1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.*
£500 National Defence Loan, 1954–58, 3 per cent. Bonds.*
£500 National War Bonds 2½ per cent., 1946–48.*

Grove-Hills Special Fund

£423, 15*s.* 11*d.* War Loan 3½ per cent. Inscribed Stock.
£695, 16*s.* 0*d.* Conversion Loan 3½ per cent., 1961.
£535 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*

Trust Funds

£1212, 13*s.* 3*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£542, 18*s.* 2*d.* India 3½ per cent. Stock.
£1004 Consolidated 4 per cent. Stock, 1967.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£540, 10*s.* 4*d.* War Loan 3½ per cent. Inscribed Stock.
£1160, 16*s.* 3*d.* War Loan 3½ per cent. Inscribed Stock.

* *Taxed at source.*

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift : In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell ; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856) : Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876) : R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877) : C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905) : Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906) : The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922) : The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922) : Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931) : A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936) (*see below*).

The Herbert Spencer Bequest (1936): Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The bequest was finally expended during 1941.

The Lindley Bequest (1937) : Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.

The Stanley Williams Bequest (1939): A. Stanley Williams, Esq., who died 1938 November 21, bequeathed to the Society all his astronomical instruments, books,

maps, photographs, manuscripts, etc., together with the sum of £200, free of legacy duty, for the reduction or publication of his observations of variable stars; and also a further sum of £100, free of legacy duty, for the furtherance of astronomy in general or of the Society in particular, in such manner as the Council of the Society may think fit. No expenditure from the fund has been made up to 1942 December 31.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1*s.* 11*d.*, of which £1480, 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £423, 15*s.* 11*d.* War Stock 3½ per cent., and £695, 16*s.* Conversion Loan 3½ per cent. 1961.

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent. War Stock, the cash balance of £17, 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this fund for the purposes of the library.

	£	*s.*	*d.*		£	*s.*	*d.*
1942 Jan. 1. Balance of Fund ...	53	15	0	1942. Purchase of Books ...	1	11	0
1942. Dividends, War Stock 3½ per cent.	10	10	0	1942 Dec. 31. Balance of Fund	62	14	0
	£64	5	0		£64	5	0

THE GOODRIDGE BEQUEST

The Goodridge Bequest (1936): Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty. The bequest has been invested in £49, 0*s.* 4*d.* War Stock 3½ per cent.

	£	*s.*	*d.*		£	*s.*	*d.*
1942 Jan. 1. Balance of Fund ...	6	17	4	1942 Dec. 31. Balance of Fund	8	11	8
1942. Dividends, War Stock 3½ per cent.	1	14	4				
	£8	11	8		£8	11	8

TRUST FUNDS

The Turnor Fund and the Horrocks Memorial Fund: In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18*s.* East Indian Railway 3 per cent. Debenture Stock. In 1876 the Society received a sum of £38, 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55, 15*s.*, and the whole now stands in £103, 6*s.* East Indian Railway 3 per cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	21	7	5	1942. Purchase of Books ...	34	8	1
1942. Dividends, East Indian Railway	8	10	6	1942 Dec. 31. Balance of Fund	4	0	6
Income Tax, 1941 April–1942 April, refunded	8	10	8				
	£38	8	7		£38	8	7

The Harry Watson Memorial Fund: In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18*s.* 2*d.* India 3½ per cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	132	0	7	1942. Purchase of Books ...	11	3	4
1942. Dividends, India 3½ per cent.	19	0	0	1942 Dec. 31. Balance of Fund: Deposited in P.O. Savings Bank ... £151 11 3			
Dividends, Agricultural Mortgage 4½ per cent.	21	14	4	Balance at Bank... 33 5 9			
Income Tax, 1941 April–1942 April, refunded	21	14	2		184	17	0
Interest on P.O. Savings Bank Deposit	1	11	3				
	£196	0	4		£196	0	4

The Lee and Janson Fund: In 1834 John Lee, Esq., LL.D., gave £100, and in 1879 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10*s.* 9*d.* East Indian Railway 3 per cent. Debenture Stock.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	62	16	5	1942 Dec. 31. Balance of Fund: Deposited in P.O.			
1942. Dividends, East Indian Railway	5	0	4	Savings Bank ... £50 10 5			
Income Tax, 1941 April–1942 April, refunded	5	0	4	Balance at Bank... 22 17 1			
Interest on P.O. Savings Bank Deposit	0	10			73	7	6
	£73	7	6		£73	7	6

The Hannah Jackson (née Gwilt) Fund: In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18*s.* 6*d.* East Indian Railway 3 per cent. Debenture Stock; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	35	12	2	1942 Dec. 31. Gift from Fund ...	25	0	0
1942. Dividends, East Indian Railway	4	13	0	1942 Dec. 31. Balance of Fund	19	18	2
Income Tax, 1941 April–1942 April, refunded	4	13	0				
	£44	18	2		£44	18	2

The George Darwin Lectureship Fund: In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	100	11	1	1942 Dec. 31. Balance of Fund:			
1942. Dividends, Consolidated 4 per cent. Loan	40	3	2	Deposited in P.O. Savings Bank ... £101 0 10			
Interest on P.O. Savings Bank Deposit	1	0	10	Balance at Bank... 40 14 3			
					141	15	1
	£141	15	1		£141	15	1

The A. G. Stillhamer Trust (1937): The late A. G. Stillhamer, Esq., F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The bequest has been invested in £491, 10*s.* War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	68	16	0	1942 Dec. 31. Balance of Fund:			
1942. Dividends, War Stock 3½ per cent.	17	4	0	Deposited in P.O. Savings Bank ... £50 10 5			
Interest on P.O. Savings Bank Deposit	0	10	5	Balance at Bank... 36 0 0			
					86	10	5
	£86	10	5		£86	10	5

The E. W. Brown Trust (1939): Dr. E. W. Brown, of Yale University, who died in 1928, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160, 16*s.* 3*d.* War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1942 Jan. 1. Balance of Fund ...	101	11	3	1942 Dec. 31. Balance of Fund:			
1942. Dividends, War Stock 3½ per cent.	40	12	6	Deposited in P.O. Savings Bank ... £101 0 10			
Interest on P.O. Savings Bank Deposit	1	0	10	Balance at Bank... 42 3 9			
					143	4	7
	£143	4	7		£143	4	7

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS TO THE LIBRARY DURING THE YEAR 1942

Astrophysical Observatory of the Academy of Sciences of the Georgian S.S.R., Abastuman
Association of Special Libraries and Information Bureaux
The British Broadcasting Corporation
Committee for the Continued Distribution of Astronomical Literature, Harvard College Observatory
Messrs. J. M. Dent & Sons Limited
The Editors of *The Observatory*
The Editors of *Sky and Telescope*
Griffith Observatory, Los Angeles
Imperial Chemical Industries
Astronomical Society of Mexico
University of Minnesota
National Bureau of Standards, Washington
National Geographic Society, Washington
Royal Geographical Society
Royal Swedish Academy of Science
Society for Research on Meteorites, Los Angeles
H.M. Stationery Office

Major George Anne
Mr. A. C. Banerji
Mr. B. F. Bawtree
Mrs. Bell
Professor F. Debenham
Mr. M. A. Ellison
Mr. V. Hase
Dr. H. Spencer Jones
Mr. V. C. Jones
Dr. C. E. K. Mees
Dr. H. T. Stetson
Dr. R. L. Waterfield
Mrs. Willett
Mr. G. Wyatt

REPORT OF THE AUDITORS FOR THE YEAR 1942

We have examined the accounts of the Royal Astronomical Society and we approve of the various items of expenditure shown.

We view with concern the disappearance of some 40 books, chiefly on the Moon, from the Stanley Williams Bequest, and suggest that greater precautions against this kind of loss be taken. One of us has compared the official list of instruments belonging to the Society with those which are not on loan to Fellows, and reported to the Council a few minor discrepancies, mostly in respect of very old instruments.

In the course of our enquiries we have received every assistance from the Assistant Secretary and, with regard to checking the list of instruments, from the porter.

C. C. L. Gregory.
G. C. McVittie.

OBITUARY NOTICES

WALTER GEORGE BELL, son of Robert George Bell, F.G.S., was born in London on 1867 July 20 and died at his home at Wandsworth Common on 1942 May 24.

From an early age he took a keen interest in astronomy which formed the subject of many articles which he contributed to magazines. In 1899 he joined the Editorial staff of the *Daily Telegraph* for which he wrote many astronomical columns; after his retirement from active work in 1936 he was still frequently consulted on astronomical phenomena. In 1927 he wrote a popular handbook for the *Daily Telegraph* for the total solar eclipse of that year, which he successfully observed himself at Southport. Another subject which attracted his pen was archæology; he wrote a book on Old London and was a member of the London and Middlesex Archæological Society of whose Council he was Chairman at the time of his death.

He married Edith Philippa Duckworth who survives him.

He was elected a Fellow of the Society on 1918 January 11 and frequently attended the Society's meetings.

WILLIAM BOWYER entered the Royal Observatory, Greenwich, in 1892 April as a computer, and was attached to the Time and Chronometer department, in which he continued throughout his period of service. In 1896 May he was appointed to a permanent post on the staff under a new scheme of appointments then introduced. Besides being one of the regular observers with the Transit Circle, Bowyer took up the observation of double-stars, doubtless influenced in his choice by the fact that Lewis, then at the head of the Time department, also had charge of the double-star observations made with the 28-inch Refractor. Bowyer soon became a skilled observer of double-stars and his interest in the work is shown by a paper contributed by him to the *Monthly Notices*: "On the orbit of Σ 2525." In the work of his department, Bowyer developed exceptional skill in the care and management of the standard clocks, as also of the Navy chronometers undergoing trial and examination. Much of the additional work connected with the supply of chronometers for the Navy during the war years 1914–1918 devolved upon Bowyer, and on the retirement of Lewis in 1917 September he was promoted assistant in charge of the department. The succeeding years were a period of great change and progress in the development of precision time-keeping, to which was added the distribution and reception of wireless time-signals. Bowyer devoted himself to these new tasks with unbounded energy. These were comparatively early days in wireless and it may not now be easy to realise how much Bowyer achieved, sometimes with inadequate resources and often with improvised apparatus.

In 1933 he contributed a paper "Note on the Registration of Annapolis Time Signals" to the *Geophysical Supplement* (vol. 1, No. 3) of the *Monthly Notices*. The installation of new free-pendulum clocks called for the exercise, on Bowyer's part, of all that practical skill which he possessed in so high a degree. In collaboration with Sir Frank Dyson, Bowyer contributed a number of papers to the *Monthly Notices* on "The Reception of W/T Time Signals" and with Dr. J. Jackson a series of papers "On the Shortt Clocks." Careful and painstaking in all that he did, he was at times almost meticulous. With him things had to be "just so." Of a generous disposition and ever ready to be of assistance to others who might come to him for help, he was greatly esteemed by all who worked with him. He retired in 1936 October after forty-four years service, in all, at the Observatory. He died 1942 January 31 and is survived by his widow. He became a Fellow of the Society on 1905 April 14.

P. J. Melotte.

JAMES RUTHVEN BROWN will be remembered widely in nautical circles as the managing director of Messrs. Brown, Son & Ferguson, Ltd. In this firm he carried on the publication and printing of *Brown's Nautical Almanac*, first published by his father in 1858. Perhaps the best and most widely known of the non-official Almanacs, "Brown's" has a much wider scope than the *Abridged Nautical Almanac*, containing tidal predictions, light lists and other navigational information as well as the purely astronomical data; as such it is very popular with the merchant service, especially for coastal traffic. J. R. Brown was particularly interested in the astronomical section and only a short time before his death he personally took a large share in its preparation from the basic data of the official Almanac.

As editor of the *Nautical Magazine*—a periodical for "those interested in ships and the sea"—he encouraged articles and discussions on methods of astronomical navigation, and throughout he maintained the high standard of interest and utility that has characterised the magazine since its appearance in 1830. Brown was closely associated with the other publishing activities of the firm, which has on its lists many tables and textbooks on astronomical navigation.

Brown's life was closely associated with Glasgow, where he was born in 1873 April and died on 1942 October 16, but his nautical interests led him to travel extensively, and yacht cruising was one of his special hobbies. He was associated with the Institution of Engineers and Shipbuilders and a member of the Incorporation of Wrights. He was also actively interested in the Boy Scout movement and became Commissioner for one of the Glasgow districts in 1921.

He is survived by his wife, a daughter and two sons, one of whom carries on the family tradition in the R.N.V.R.

He was elected a Fellow of the Society on 1927 April 8.

GEORGE DOUGLAS BUCHANAN was born in 1874, a member of the well-known West of Scotland distilling family. His interest in astronomy is indicated by his active membership of the West of Scotland Branch (later the Scottish Branch) of the British Astronomical Association from 1910; he served as President 1935–37 and Vice-President on several occasions.

His deepest interest was in international language, and he was a member of the British Esperanto Association from its inception in 1904, serving as President from 1936 to his death on 1941 August 26. He interested himself in the dissemination of elementary Astronomy and many other subjects through Esperanto, and wrote in various papers devoted to that language. He did a great deal of unobtrusive social service, was a life member of the Royal Philosophical Society of Glasgow and an officer of the British Empire Air League. He was an excellent conversationalist, a good friend, generous, kindly and a fine chairman.

He was elected Fellow of the Society on 1933 April 12.

T. L. MacDonald.

ANDREW RUSSELL FORSYTH, Emeritus Professor of the Imperial College of Science and Technology, South Kensington, died on 1942 June 2. His age just fell short of eighty-four, as he was born (at Glasgow) on 1858 June 18.

He was educated at Liverpool College and at Trinity College, Cambridge. His student career at Cambridge was brilliant: he was Senior Wrangler, and First Smith's Prizeman in 1881, in which year he was elected to a prize fellowship at Trinity. The following year he became professor of mathematics at University College, Liverpool, but two years later, in 1884, he returned to Cambridge as a lecturer of his college and of the university. In 1895 he became Sadleirian Professor of Pure Mathematics at Cambridge in succession to Cayley; he held this post until 1910. In 1913 he accepted the headship

of the department of mathematics at the Imperial College, combining the direction of two previously separate schools (one in the Royal College of Science, the other in the City and Guilds Engineering College) headed by Professors Perry and Henrici, who retired nearly at the same time. The Great War of 1914–18, and its aftermath, interrupted his plans for building up a new honours school of mathematics at South Kensington, and he retired from his chair in 1923, after ten years' tenure, on attaining the age limit of sixty-five.

While still in his twenties he attained a reputation as a pure mathematician that extended far beyond the borders of his own university and country. His distinguished researches led to his election as a Fellow of the Royal Society at the early age of twenty-seven, and eleven years later he was awarded a Royal Medal of the Society. In the same year he was President of Section A of the British Association at its Toronto meeting, a distinction which he held a second time in South Africa in 1905. He was President of the London Mathematical Society, 1904–6.

Besides making important original contributions to pure mathematics, he rendered a service of special value to his university in breaking the bonds of the isolation of its mathematical school, during the latter part of the nineteenth century, from the great continental movements of thought in the subject. By his lectures and his writings (he was a prolific author of mathematical books) he widened the knowledge and outlook of his colleagues and students, and stimulated a revival of pure mathematical learning and research in England.

For many years he was regarded abroad as the leader and representative of English pure mathematics, and honours from universities and academies the world over were bestowed upon him. He maintained many personal and official international contacts; he travelled much and was an accomplished linguist.

Professor Forsyth became a Fellow of the Society on 1895 May 10, but was not a frequent attender at our meetings, and never served on the Council. He made one contribution to *Monthly Notices* in 1921, entitled "Notes on the path of a ray of light in the Einstein Relativity Theory of gravitational effect."

S. CHAPMAN.

JOHN HENRY HINDLE was born at Edenfield, in the Rossendale valley of Lancashire, of Scottish stock, on 1869 November 2, and was elected to Fellowship of the Society on 1922 June 22.

He was a shrewd Lancashire ironmaster, generous of heart and hand, with all the many virtues of his race: a man of robust intelligence, inexhaustible patience and infinite resource. At the date of his death he was the governing director of the firm of Hindle, Son & Co., Ltd., Engineers, of Witton, Blackburn, where he produced, based on his own and his son's patents, electric and other baling presses, and powerful wide looms for the weaving of cotton and woollen dryer felts for use in the paper-making industry. He was indeed the first person directly to apply electrical power to the generation of mechanical pressure for baling loose materials, and the convenience of this machine has been widely recognized.

Apart from elementary education at the local school at Edenfield, Hindle was practically self-taught. At the age of twelve years he commenced work as a "half-timer" in the textile industry, and upon leaving school at the age of thirteen went into the mill office where his father was secretary and cashier. During this period he worked in an iron foundry and workshop in his spare time and developed very early his interest in engineering, particularly on the electrical side. About 1895 he had attained the position of electrical consultant on hoisting machinery and electrical motors and dynamos. He developed and patented automatic control gear, an electro-magnetic brake and an emergency safety mechanism for use in electric passenger and goods lifts.

In 1910 he courageously started in business for himself as a practical engineer in

Manchester, removing in 1918 to Haslingden and afterwards to the present Union Engineering Works, Blackburn, where, with the assistance of his only son Thomas, who survives him, he built up a considerable business in textile engineering.

As his major hobby the production of telescope mirrors appealed to him because of his love of the delicate and precise in science and art. Although not physically a big man he had a wonderful facility in the handling of large specula. Some years ago he was described in the *Manchester Guardian* as "one of the leading optical experts of the time." He produced and mounted many Newtonian and kindred mirrors of all sizes, the largest being the 20½-inch made for Dr. W. H. Steavenson, the 25-inch which he used himself for the delight of his friends, and the 30-inch which is being mounted at the Cambridge University Observatory by arrangement with Sir Arthur Eddington. This instrument is to be available for the Observatory staff until such time as Dr. Steavenson is free to put it to full use. It is described in detail by Hindle himself in the *Scientific American* for 1939 September. Notwithstanding the magnitude of these instruments Hindle always considered himself a "pure" amateur, never profiting financially by his hobby, but always shrewdly placing his telescopes where he knew they would do the best work.

His principal contributions to the craft were:—

(*a*) "The Compound Telescope—Cassegrainian and Gregorian Types."

(*b*) "The Mechanical Flotation of Mirrors."

(*c*) "How to Make a Diagonal for a Newtonian Reflector."

(All appearing in permanent form in *Amateur Telescope Making* and *Amateur Telescope Making: Advanced.*)

(*d*) "A New Test for Cassegrainian and Gregorian Secondary Mirrors." (*M.N.*, **91**, 592, 1931.)

This new test was considered by Professor Sampson to be a great improvement on other practice, and led to Hindle's being commissioned to make a new 19½-inch convex secondary for the 72-inch reflector at the Dominion Observatory, B.C., to be subjected to the new test. I cannot find, however, that this convex was actually completed.

Hindle designed his own "ovoid stroke" grinding and polishing machine but refused to patent it. It is described in *Amateur Telescope Making* and has become justly popular in the United States of America. A machine of its type is installed at the Kyoto Imperial Observatory, Japan.

Hindle was a world-wide traveller. His unique business took him constantly to the Continent. He visited South Africa, the United States and Canada, the last two on many occasions. At such times he always made it convenient to visit the great observatories, where his acquaintance with the optics of reflection made him *persona grata* with those in control. He was present at the pouring of the 200-inch disc for the Mount Palomar reflector, an experience which he afterwards described to the present writer in vivid phrases and good Lancashire accent.

Hindle died at his home in Blackburn on 1942 May 17, at the age of seventy-two. He is buried with his wife (who predeceased him by twenty-two years) in Helmshore churchyard, and his memorial bears the simple inscription of his devoted daughter, who survives him:

"He helped them to look at the stars."

WILLIAM PORTHOUSE.

JOSEPH LARMOR was born at Magheragall in Co. Antrim on 1857 July 11. He graduated at Queen's College, Belfast, and proceeded to St. John's College, Cambridge. He was Senior Wrangler in 1880, the second place being taken by J. J. Thomson. He immediately became Professor of Natural Philosophy at Queen's College, Galway, and Fellow of St. John's College. He remained at Galway for five years, and then returned

to St. John's College as College Lecturer. In 1903 he became Lucasian Professor on the death of Sir G. G. Stokes. He was knighted in 1909. He retired in 1932, but stayed in Cambridge for a year or two before going back to Northern Ireland, where he remained until his death on 1942 May 19, except for one brief visit to Cambridge.

His chief work, *Æther and Matter*, was published in 1900, and incorporated much of three mammoth papers in the *Philosophical Transactions*. A full account of this part of his work has been given by Sir Arthur Eddington in the Royal Society's Obituary Notices. It may be said to have marked the end of the various mechanical models of the ether that crowded nineteenth century physics. Larmor's model had a gyroscopic stability and enabled him to explain why light can show only transverse waves without longitudinal ones. It could be imitated by a model containing a sufficient number of gyrostats; it is not very clear from his writings whether he wanted it to be. The essential point was that he was able to assign a form to the energy that would give the right differential equations. He continually insisted on the necessity of reducing everything to the Principle of Least Action, which is out of fashion these days. But the principle has the great recommendation that when a form has once been chosen for the energy it is possible to see at a glance what is relevant; all irrelevant quantities automatically cancel. He made the outstanding discovery that a certain linear transformation of the co-ordinates and time leaves Maxwell's equations unaltered to the second order of small quantities, the transformation being that completed by Lorentz and shown to be exact. Larmor's contribution covers the whole of the experimental facts within the experimental uncertainty, and if verifiable prediction is a consideration in the assignment of proper names the transformation might well be called the Larmor-Lorentz transformation. From this result the theory of relativity sprang. Larmor was also the principal creator of classical electron theory—the electron was predicted long before Thomson observed it. In particular he gave the classical theory of the Zeeman effect.

Not many of his papers are directly astronomical or geophysical. He gave the general form of the correction of the period of the Eulerian nutation for the elasticity of the Earth, a further correction for the fluidity of the ocean, and the equations for the effects of changes of the products of inertia on the axis of instantaneous rotation. In two papers with Col. E. H. Hills (later Grove-Hills) he adopted the standpoint that the correct treatment of the problem of the variation of latitude is to use the observed displacements to calculate the changes of the direction of the axis of maximum moment of inertia with respect to the Earth's surface. In other words, instead of separating out the annual component directly from the observations by harmonic analysis, they treated all disturbances together, whether regular or irregular, by numerical differentiation of the observed displacements. The corresponding free vibration has a period of 14 months, and consequently a disturbing couple produces a much larger displacement if its period is a year than a couple of equal amplitude with a shorter period. Their treatment was equivalent to estimating the couples from the displacements, and therefore the annual terms were much less conspicuous in their results than in the original data, being comparable in magnitude with the irregular variations lasting a few months. The chief value of their work is that it showed the importance of this background of irregular variation, which is still not understood.

Larmor also offered two suggestions about the Kimura term in the variation of latitude, one that it is due to the annual melting of polar ice, the other that it is due to local refraction over the dome of the telescope.

One rather long paper, with N. Yamaga, deals with the analysis of sunspot frequencies, and maintains that a regular periodicity of 11·1 years dominated the whole record of 160 years except for a discrepant interval from 1776 to 1798. One fundamental paper showed that electric conductivity in the upper atmosphere would not account for the transmission of electric waves around the Earth, and appealed to the oscillations of free ions instead. These could produce much more reflexion with less damping.

His papers are difficult to read on account of diffuseness and prolixity of style. The same applied to his lectures, which suffered badly by comparison with those of Bromwich on similar subjects; though it is probable that Bromwich himself had been greatly inspired by Larmor, he was a far better expositor of Larmor's ideas than Larmor was. In conversation and at a committee he could be quite clear—sometimes all too clear. He dearly loved an argument, and never forgot that he came from Northern Ireland. Of his handwriting it can only be said that few people could deal with it better than the compositor who rendered "it would be" as "*t* cosec *C*."

He always maintained an interest in public affairs, resembling in this his greatest predecessor. He represented Cambridge University in Parliament from 1911 to 1922, and afterwards was a frequent correspondent to *The Times*. The present writer remembers vividly his plaintive query over the Food and Drugs Act about whether there was any scientific evidence that boric acid did anybody any harm.

He was secretary of the electors to the Isaac Newton Studentship for a long period, and in that capacity his indirect influence on astronomy was much greater than appeared through his personal contributions. He was always helpful to the young research worker, in spite of his underlying belief that real science came to an end with Lord Kelvin.

He was elected a Fellow of the Society on 1899 February 10.

HAROLD JEFFREYS.

ARCHIBALD WILLIAM TINDALL-LUCAS was elected Fellow of the Society on 1919 November 14, and died on 1941 March 13, at his home at Woking where he and his wife lived for many years. He led a quiet life—for forty years largely devoted to his business career in banking, and his hobby of collecting genealogical data. Although interested in astronomy he seems to have left no record of an active part in it.

GEORGE TYRRELL McCAW, who died on 1942 October 17, was one of the leading and best known geodesists in the Empire and the first editor of the *Empire Survey Review*.

The elder son of the late Robert McCaw of Lurgan, Co. Armagh, Northern Ireland, he was born in 1870 and graduated in arts and engineering from Trinity College, Dublin, in 1893, becoming M.A. in 1898. His first appointment after leaving the University was with the Irish Land Valuation Department, with which he remained until 1903 when he accepted an appointment as assistant on an extension into Northern Rhodesia of the Geodetic Survey of South Africa. This extension, which was undertaken on the initiative of the late Sir David Gill, at that time H.M. Astronomer at the Cape, formed part of a measurement of an arc of the 30th meridian. The work lasted until 1906 when financial conditions at home made it necessary for it to be closed down.

Early in 1908, after a short period of employment on the measurement of a base line in Sweden, McCaw joined Major (now Brigadier) E. M. Jack, R.E., on a continuation in Uganda of the arc of the 30th meridian on which he had been engaged in Rhodesia. This survey came to an end in 1909, and in 1910 he proceeded to Fiji to take charge of the Trigonometrical Survey of that Colony. The field work of this was completed in 1915, and he then returned to England to finish the computation and adjustment of the observations and to compile a complete report. This was published in two volumes in 1917 and earned him much credit from those who were competent to appreciate its merits.*

Having completed his report on the Fiji survey, McCaw was commissioned in the Royal Engineers in 1917 and proceeded at once to France where he acted as geodetic adviser to the Survey Directorate at G.H.Q. In 1919 in order to take advantage of his outstanding knowledge, ability and experience, he was given a special civilian appoint-

* "Report of the Trigonometrical Survey of Fiji," by G. T. McCaw. Vol. I (Viti Levu). Vol. II (Vanua Levu and Tavenui). E. Stanford, Ltd., London, 1917.

ment with the Geographical Section, General Staff, War Office, where he acted as adviser on all matters of a geodetic nature. He remained in this appointment until 1936 when he retired on reaching the age limit. During this period he acted as one of the joint secretaries of the Colonial Survey Committee, now the Colonial Survey and Geophysical Committee, and in this way came into contact with surveyors from all over the Empire and with the problems that confront them, while his name became generally known as that of a geodesist of outstanding ability. He was also secretary of the Air Survey Committee from the time of its foundation in 1922, and he attended, as one of the British delegates, the various triennial assemblies of the International Union of Geodesy and Geophysics, that were held after the conclusion of the last war.

In 1931, as a result of a recommendation made at a Conference of Empire Survey Officers, it was decided to found a semi-official journal—the *Empire Survey Review*—in which articles and papers on survey and geodetic problems could be printed and circulated among Colonial and Empire surveyors. The editorship of this Review was offered to McCaw and he remained editor (and, it might be added, chief contributor) until the time of his death.

McCaw's ability and mathematical attainments were great and he was the author of numerous papers. Most of his writings are contained in official publications or in the pages of the *Geographical Journal* or the *Empire Survey Review*. His able report on the Trigonometrical Survey of Fiji has already been mentioned. He also had much to do with the preparation of reports and textbooks issued by the Geographical Section, General Staff, such as the "Report of the Measurement of an Arc of Meridian in Uganda," "Manual of Map Reading, Photo Reading and Field Sketching," etc. He also collaborated with F. A. Cazalet in the translation from the German of Dr. O. von Gruber's well-known book on *Photogrammetry*, which was published in 1922.

McCaw was a man of strong personality and great personal charm of manner. His mathematical skill and his mastery of all that pertained to his chosen subject became universally recognised and appreciated by his professional colleagues; his advice on all sorts of survey and geodetic problems was in constant demand, and, when asked for, was freely and generously given. Wherever he went he was liked, respected and admired, and he will be missed, and his death regretted, by a host of friends scattered all over the world.

He was elected a Fellow of the Society on 1906 March 9.

J. CLENDINNING.

THEODORE EVELYN REECE PHILLIPS was a son of the Rev. Abel Phillips and was born at Kibworth, Leicestershire, on 1868 March 28. He was educated at Yeovil Grammar School and at St. Edmund's Hall, Oxford, where he took his B.A. in 1891. In the same year he was ordained and became curate at Holy Trinity, Taunton. Taking his M.A. degree in 1894, he was appointed in 1895 to the curacy of Hendford, Yeovil, at that time his father's parish. Here he stayed until 1901, when he took a curacy at St. Saviour's, Croydon. In 1906 he became curate at Ashtead, Surrey, where he remained until 1916, when he was appointed vicar of the neighbouring parish of Headley. Early in 1940 his health began to break down and he resigned the living in 1941 January. After little more than a year, spent in retirement at Walton-on-the-Hill, near Headley, he died on 1942 May 13, in his seventy-fifth year.

Phillips's astronomical career dates from the period of his first curacy. At that time he was already actively interested in meteorology, and in 1895 a member of his congregation, knowing of his scientific leanings, made him a present of a 3-inch Grubb refractor. By the following year he was in possession of a $9\frac{1}{4}$-inch altazimuth reflector and had started serious work on the planets. Later, while at Ashtead, he replaced the $9\frac{1}{4}$-inch with a $12\frac{1}{4}$-inch Calver equatorial, and in 1911 erected there an 8-inch Cooke equatorial refractor (the Coleman telescope) which had been lent to him by the Society.

This instrument, with its excellent mounting and clock-drive, he found more suited to micrometrical work on the planets than the reflector, and with it he also embarked on a regular programme of double-star measures, the fruits of which are shown in a long series of communications made annually to the *Monthly Notices*. This work was done with characteristic care and accuracy and, as regards the closer pairs, probably marks the limit of what can be usefully achieved in this direction with a relatively small instrument. He continued to use the 12¼-inch, with the 8-inch, for the planets until 1927, when he substituted, on the same mounting, the 18-inch With reflector that had been lent to him some years earlier by the British Astronomical Association.

It is as a planetary observer and draughtsman that Phillips will be chiefly remembered. His work on Jupiter was especially outstanding, and was probably more thorough and extensive than that of any of his predecessors or contemporaries. For thirty-three years, from 1900, he directed the Jupiter Section of the British Astronomical Association, and the results of his work are to be found in the sectional *Memoirs* published during that period. In his study of the surface-currents of the planet he made more than 30,000 separate observations of the transit times of various markings, besides making regular measures of the latitudes of the belts with the micrometer of the 8-inch refractor.

Though the name of Phillips will always be particularly associated with Jupiter, his work on Mars was, in the opinion of many, at least as distinguished. He observed the planet at every opportunity during all the oppositions from that of 1896, and his drawings, made most skilfully with pencil and stump, were certainly among the most beautiful and accurate of those adorning the *Memoirs* of the Mars Section of the B.A.A. But the great majority of his sketches, of both Mars and Jupiter, remain unpublished in his manuscript note-books. Like his measures of double stars, they show the extreme limits attainable with moderate apertures by an observer of really high skill, and each is a model of what a planetary drawing should be.

In the midst of his work on planets and double stars, Phillips found time to make occasional estimates of faint variable stars; but he was not a regular worker in this field, and his outstanding contribution to variable-star astronomy consists of a theoretical investigation of the light-curves of about 80 long-period variables, published in the form of a Presidential Address to the British Astronomical Association in 1916. By this research, undertaken at the instigation of the late Professor Turner, he succeeded in demonstrating that the long-period variables tend to fall into two groups, as shown by harmonic analysis of their light-curves.

Phillips was not a serious or regular eclipse observer, but he went to Spain for the eclipse of 1905 August 30; to the U.S.A. for that of 1932 August 31; and to the Mediterranean for that of 1936 June 19. On all three occasions he was favoured with good weather conditions, but he was unlucky in Yorkshire in 1927.

Quite apart from his original contributions to Astronomy, both observational and theoretical, Phillips did much to popularise the science by the lectures which he gave in various parts of the country over a period of many years. He had a vigorous, almost dramatic way of presenting the subject, and his infectious enthusiasm was the means of bringing many a useful recruit to the ranks of the serious workers in astronomy.

Throughout his astronomical career he maintained his early interest in meteorology, keeping regular records of temperature and rainfall, which he subjected to harmonic analysis shortly before his death.

His contemporaries were not slow in recognising his merits and ability, and probably not a few would be inclined to regard him as in some respects the most distinguished amateur astronomer that our country has ever produced. Many well-deserved honours and appointments came to him in the course of his active career. He served almost continuously on the Council of the Society from 1911 until his death, was Secretary from 1919 to 1925, and President from 1927 to 1929. He was awarded the Jackson-Gwilt Medal of the Society in 1918, and in 1930 received the Goodacre Medal of the

British Astronomical Association, of which he had been President from 1914 to 1916. From 1925 to 1935 he was President of Commission 16 of the International Astronomical Union, an indication of the esteem in which he was universally held as a planetary observer. In 1922 he was chosen by the Archbishop of Canterbury to represent the Church of England on the commission concerned with the fixation of Easter; and later he served on the committee appointed to deal with calendar reform. Finally, only a few weeks before his death, the honorary degree of D.Sc. was conferred upon him by his own University of Oxford, an honour which he appreciated very highly.

While the achievements of Phillips the astronomer commanded the admiration of his fellow-workers, Phillips the man inspired real affection in the hearts of all who were privileged to count themselves among his personal friends, for he was indeed a most lovable man. Always modest with regard to his own attainments, he was warmly generous in his appreciation of the work of others, and in the excuses he was so ready to make for their shortcomings. In particular he would go to great lengths to avoid any occasion of discouragement to a beginner, and his friends often marvelled at the patience he showed when dealing with those whom, at the worst, he would describe merely as "rather tiresome."

The vigorous enthusiasm of his speech and manner was in itself a most cheering and stimulating thing. His verbal descriptions of various incidents in his observing career were always most vivid, and there was something quite thrilling in listening to his spirited accounts of nights when the seeing had been "absolutely superb," or when Jupiter had shown a "wealth of detail" which had been a "perfect revelation." He always saw the funny side of things, and even when the joke was against himself his laughter would be just as hearty.

He seemed genuinely to enjoy his life and all the simple pleasures that it brought him. He loved the country-side and the wild flowers, whether Alpine or English, and it was hard to find one to which he could not put a name.

As a young man he had been a good cricketer, but be injured a muscle in his leg in a walking-race with his vicar at Ashtead, and after this his activities as a player were practically brought to an end: but he kept up his interest in the game, and, when up in London for the day, he often contrived to combine a visit to Burlington House with an hour or two at Lord's or the Oval.

Like Herschel, Phillips slept little or not at all during the hours of darkness when observing conditions were good, and yet he seldom showed any marked signs of fatigue. Nor, for all his scientific activities, did he ever neglect his duties to his Church and parish. As was remarked in the Latin oration, delivered on the occasion of the conferment of his honorary degree, "his happy lot it was to keep the Heavens under constant watch, while scorning not the things of Earth; alone by night to tread the starward way, to show it forth to all men in his daily life."

In 1906 Phillips married Mellicent Kynaston, by whom he had one son. He was elected a Fellow of the Society on 1899 May 12. W. H. Steavenson.

WILLIAM JOHN ROBERTS was born on 1867 April 16 in Dungannon, Co. Tyrone. From early boyhood he showed a great interest in astronomy, to which his devotion in later years to lecturing, writing and practical observation bore witness. With the help of his friend the Rev. W. F. A. Ellison of Armagh Observatory, he constructed his own observatory with a $5\frac{1}{4}$-inch refractor. He possessed a gift of vivid speech which he delighted to use, by lecture or conversation, to inspire young and enquiring minds with a similar interest in astronomy. In addition to lectures in Ulster, his name was known for monthly articles which proved to be a popular feature in the *Irish Independent*. He was elected a Fellow of the Society on 1918 November 8, and also joined the Société Astronomique de France.

As an ardent Methodist he devoted over fifty years of his life to work as a local preacher. He was deeply interested in British Israelism and in this connection made a special study of the Bible. His upright mind and unworldly interests gained him the admiration and respect of many friends whom he inspired with faith in days of war and evil.

He married Anna Matilda Tate in 1905, and died at his home at Tullyroan, Co. Armagh, on 1942 August 9. He is survived by his widow and three daughters.

FRANCIS JAMES WARDALE was amongst the senior Fellows of the Society, having been elected on 1888 January 13. He was born in 1856 at Orcheston St. Mary Rectory, Wilts, and was a Scholar of Clare College, Cambridge, where also his father, brother and son were educated. All were rowing men, and Cambridge rowing was throughout his life one of his greatest interests, which included equally cricket, astronomy, meteorology and field botany: he was an observer for "British Rainfall" for many years. After taking his degree in mathematics he studied law, and entered the Civil Service in the then Office of Woods, Forests and Land Revenue. He resided at Knebworth, Herts, until failing sight forced him to retire in 1900; and during this period he made a special study of Mars and of double stars. After he became blind he returned to Wiltshire, where he remained with short intervals until his death at Salisbury on 1942 March 14. In 1892 he had married, and had a son and two daughters, to whom, despite his blindness, he imparted an interest in astronomy, borrowing a $3\frac{1}{2}$-inch telescope from the Society for this purpose. J. F. B. WARDALE.

HEBER DOUST CURTIS, Professor and head of the department of Astronomy of the University of Michigan and Director of the University of Michigan Observatory, died at Ann Arbor on 1942 January 9, in his seventieth year. A man of great versatility and with wide interests, it was almost by chance that he made astronomy his life-work. Born on 1872 June 27 at Muskegon, Michigan, he wished to enter Annapolis but did not reach the required height. Being interested always in things mechanical, he then desired to become an engineer. The parental wish was that he should enter the ministry, but this did not appeal to Curtis, though not from any aversion to religion, for he was always a devout man. It was perhaps as a matter of compromise that he took up the study of the dead languages, Latin, Greek, Hebrew and Sanskrit. That he retained his interest in and knowledge of languages was shown by a recent paper on "An ephemeris of 467 A.D."

After graduating at the University of Michigan in 1892 he taught for a year at the Detroit High School; then in 1894 he was appointed Professor of Latin at Napa College, California. In 1897 he accepted a post as Professor of Mathematics and Astronomy at the College of the Pacific at San José. He remained in this post for three years, serving during the summer vacations as a volunteer assistant at the Lick Observatory. It was probably the experience that he gained there and the encouragement that he received from the Director, E. S. Holden, that finally decided him to make his career in astronomy.

In 1900 he applied for the Vanderbilt Fellowship in Astronomy at the University of Virginia, which was awarded to him. He had married in 1895 and at the time of the award of the Fellowship had two children. To accept a Fellowship worth $350 a year required mutual courage on the part of his wife and himself and called for the exercise of much ingenuity. Before taking up the Fellowship, he assisted Campbell and Perrine in the Lick Observatory observations at the total eclipse of 1900 May in Georgia. In 1901 he accompanied the Naval Observatory eclipse expedition to Sumatra. Curtis took part in eleven eclipse expeditions in all. He was a great asset to any eclipse party; his mechanical skill and ingenuity were invaluable in the mounting and adjusting of

instruments and apparatus, and in surmounting the difficulties that are liable to be encountered in field work. His linguistic ability and the facility with which he could pick up a working knowledge of a language proved useful in countries such as Sumatra and Russia. The writer first met him in Russia after the eclipse of 1914 August; Campbell, Perrine and Curtis formed the Lick Observatory party on that occasion.

On obtaining the Ph.D. degree at the University of Virginia in 1902 he was appointed assistant at the Lick Observatory and in 1904 was promoted Assistant Astronomer. At the end of 1905 he relieved W. H. Wright, in charge of the D. O. Mills Southern Station of the Lick Observatory at Santiago, Chile. His work at this time was necessarily concerned mainly with the determination of radial velocities and the investigation of the orbits of spectroscopic binary stars. He also secured excellent series of photographs of comet Morehouse, 1908 *c*. In 1909 he returned to Mount Hamilton and held the rank of Astronomer. There he obtained a particularly fine series of photographs of Halley's Comet. It was in the years that followed that his most important contributions to astronomical knowledge were made. He was in charge of the Crossley reflector and undertook studies of the nebulæ. The *Lick Observatory Publications*, Vol. XIII, 1918, contains three important papers by Curtis. The first contained a catalogue and description of 762 nebulæ and clusters photographed with the Crossley reflector. All nebulæ that were undoubtedly of the diffuse or planetary type were specially indicated. Barred spirals were called ϕ-type spirals. Curtis believed that "all the many thousands of nebulæ not to be definitely classed as diffuse or planetary are true spirals, and that the very minute spiral nebulæ appear as textureless disks or ovals solely because of their small size." He remarked that the Andromeda nebula would have a similar appearance, if removed to a sufficiently great distance. The number of nebulæ revealed on the Crossley plates was made the basis of a careful statistical discussion of the minimum total number of the nebulæ, leading to the conclusion: "I see no reason, at present existing, for changing the estimate made in this paper, that at least 700,000 and very probably 1,000,000 small spirals are within reach of large reflecting telescopes."

The second paper was a study of occulting matter in spiral nebulæ. Curtis showed that the occurrence of bands of occulting matter was a relatively common characteristic of the spiral nebulæ. He drew an analogy between them and our galaxy, where occulting matter near the galactic plane obliterates the spirals in or near the projection of the galactic plane. He pointed out that occulting or non-luminous matter was frequently to be found outside the luminous portions of the gaseous nebulæ; that many starless regions or "dark nebulæ" were produced by obscuring matter; and that the stationary lines of calcium, observed in many spectroscopic binaries, could be attributed to clouds of non-luminous calcium.

These studies convinced Curtis that the spiral nebulæ were extra-galactic objects: "island universes." He discovered several novæ in spiral nebulæ and used them to derive rough estimates of distance, which were subsequently confirmed as to their order of magnitude by the use of Cepheid variables. The general tendency amongst astronomers at this time was to regard the spirals as galactic objects. The effects of galactic absorption, so clearly pointed out by Curtis, had not been generally recognised; the peculiar grouping of the spiral nebulæ around the galactic poles, though the reason for it was not understood, was thought to indicate an association with our galaxy. For a time, Curtis was almost alone in insisting that the spiral nebulæ were extra-galactic objects. His evidence seems now to be very clear and convincing. But unfortunately the Crossley reflector was just not sufficiently powerful to provide the conclusive observational confirmation that was needed, and it was not until Hubble's work with the 100-inch reflector provided such confirmation that Curtis was finally proved to be right.

The third paper dealt with the planetary nebulæ and was based on a series of photographs of all such systems north of 34° south declination. Illustrations of all these objects were given in the volume, together with descriptions. In the case of the small

objects, because the details of the structure were apt to be obscured by effects of the grain of the plate in enlarging and because of the great contrasts in brightness, composite crayon drawings were used as the most satisfactory method of showing in one picture all the details visible in all the negatives. Curtis made an exhaustive discussion of the forms of these systems, of their number and evolutionary classification. This paper has been invaluable for reference purposes in all later work on the planetary nebulæ.

During the war of 1914–18 Curtis was absent from the Lick Observatory, at first teaching navigation at San Diego and later working at Washington in the Optical Section of the Bureau of Standards.

In 1920 Curtis left the Lick Observatory to succeed Schlesinger as the Director of the Allegheny Observatory. In his ten years there he took part in five eclipse expeditions. In 1925 he secured the first spectrograms of the coronal and flash spectra in the infra-red, and he made several attempts to obtain interference fringes in the image of the green coronal line. He regularly took parallax duties with the 30-inch Thaw refractor, which he freed from a troublesome periodic error in the driving worm. He provided a well-equipped workshop and made a number of instruments. Curtis was never happier than when he could be working at the lathe, engaged on some mechanical construction.

In 1930 he returned to Michigan as Director of the Michigan Observatory in succession to R. H. Curtiss, who had succeeded Hussey barely three years previously. The Lamont-Hussey 27-inch refractor had recently been installed at Bloemfontein in South Africa for the observation of southern double stars and plans were under consideration for moving the Observatory from Ann Arbor to a more favourable site. It was to be the task of Curtis to plan and equip the new Observatory. Into this he threw himself heart and soul, and completed the plans, including those of an 85-inch reflector. But then the depression came and all development was indefinitely postponed. The work at the Southern Station would have had to terminate, if financial assistance had not been given by the South African Government and the Municipality of Bloemfontein. A pyrex disk was ordered, however, from the Corning Glass Co. The first disk proved defective and the opportunity came, in pouring a second disk, of obtaining a 97-inch disk at slightly increased cost. This offer was accepted and the 97-inch disk was successfully cast, annealed and delivered to Ann Arbor. The designs for the mounting will need some modification in order to carry the larger disk.

The period of his directorship will be remembered by the development of the McMath-Hulbert Observatory at Lake Angelus which will be permanently associated with the Michigan Observatory. Curtis took a great interest in the ingenious and beautiful equipment designed by the McMaths, and there is no doubt that this equipment benefited from his experience in the design and construction of fine instruments. The success that was obtained, particularly in the study of solar prominences by the application of cinematography, gave him great pleasure and he always enjoyed taking visitors to Ann Arbor out to Lake Angelus to see the equipment.

Curtis took his professional duties seriously. He was an able teacher, with the gift of clear exposition and the facility of smoothing away difficulties, and he was much in demand as a popular lecturer on astronomy. He was interested in people and was a good companion and a genial host. He would take a visitor many miles in his car for an afternoon jaunt, to see Detroit and across the bridge into Canada; it was an experience to be remembered, for the speed was more often above than below sixty miles an hour. It seemed to provide some outlet for his abounding energy.

Curtis was of English extraction and was proud of the fact. He was a member of the National Academy of Sciences and of the American Philosophical Society. He was elected an Associate of the Royal Astronomical Society on 1921 June 10.

H. Spencer Jones.

HERMANN ALBERT KOBOLD, elected an Associate of the Society on 1912 June 14, was born on 1858 August 5 in Hanover, Germany, and received his doctor's degree in 1880 from Göttingen. For a short while he was attached to the observatory of O'Gyalla, Hungary, and from 1886–1902 to the observatory and University of Strasbourg. In 1902 he moved to Kiel, where he acted as Observator at the Observatory and Professor at the University until his retirement at the end of 1925. After the death of Professor Kreutz, he edited, from 1907–1938, the *Astronomische Nachrichten* and was chief of the bureau of astronomical telegrams, which before World War I was the only one of its kind. He died on 1942 June 11 at the age of eighty-three.

Kobold took part in the German expeditions for the observation of the transits of Venus in 1874 and 1882. He did some work in different fields of stellar astronomy, for instance extensive investigations of proper motions for the purpose of determining the solar apex, and was among the pioneers who determined the position of the galactic pole. He wrote several astronomical books, the best known being the excellent textbook on stellar astronomy *Der Bau des Fixsternsystems* (Braunschweig, 1906), which, although now out of date, supplies information relating to the early phases of stellar astronomy frequently omitted in modern textbooks, but of value to those interested in the historic development of modern astronomy.

However, as a pupil of Klinkerfues, Kobold did his principal work in classical astronomy. He computed numerous orbits and ephemerides for comets and minor planets, and for many years he published yearly reviews in the *Vierteljahrschrift der Astronomischen Gesellschaft* of the discovery of new comets and of the status of orbit computations for both new and periodic comets. These reviews, like all of his work, were characterised by great accuracy and reliability. Without doubt his main contribution to astronomy was his careful editing throughout thirty-one years of the *Astronomische Nachrichten*, which ranks among the leading astronomical journals of the world.

Kobold was a typical German professor of the old school, quiet, most dignified and of great integrity. Although handicapped in later years by growing blindness he devoted his energies most diligently to his editorial duties and succeeded in maintaining the high standard of reliability of his journal. In his later years he may have been a little hesitant in accepting new ideas. Likewise his small black-coated figure with the flowing, professorial beard, may have seemed somewhat unapproachable to the younger generation who lacked ability duly to appreciate the sterling qualities typical of the old German scholars, which for years rendered them the superior compilers of reliable data.

His wife died a few months before him; he had three sons, one was killed in the war of 1914–18 and the other two survive him. JULIE M. VINTER HANSEN.

PROCEEDINGS OF OBSERVATORIES

Royal Observatory, Greenwich
(Director, Dr. H. Spencer Jones, F.R.S., Astronomer Royal)

During the first few months of the year, some of the damage which the Airy transit circle and building had received as the result of enemy action was made good. The chronograph was repaired and the Cottingham Clock was brought into use again. Observations on a restricted scale were resumed with the instrument on May 26. These consist primarily of observations of the Sun and Venus, together with stars in both the clock and azimuth lists. Observations of the Moon and of other planets are made if circumstances permit. Up to the end of the year 80 observations of the Sun, 29 of Venus, 3 of Vesta and 2 of the Moon had been obtained, together with 387 observations of clock stars and 242 observations of azimuth stars.

The results of observations of stars during the years 1931–40 will be published later as the First Greenwich Catalogue for 1950. The ledgering of observations made in the years 1931–38 of stars in the zone $+0°$ to $+24°$ Dec. has been completed and computation of the places for 1950·0 is in progress. Ledgering of the observations made in 1939–40 is held up until corrections for variation of latitude are available.

The measurement of the plates obtained with the Cookson Zenith Telescope, up to the time when observations were suspended, has been completed. The results are being discussed for the derivation of the latitude variation.

A $4\frac{1}{2}$-inch refractor of 48 inches focal length was mounted during August in the astrographic dome, for the observation of occultations, to supplement the observation of the Moon with the transit circle. Up to the end of the year, though practically all occultations predicted in the *Nautical Almanac* were watched for, only one disappearance was observed, because of very cloudy skies.

During the year 200 plates were measured for the determination of stellar parallax. Five determinations of parallax were completed. A number of plates have been measured of stars for which sufficiently complete series for the determination of parallax are not available: by doing this, the value of the material in hand will be ascertained. Two papers, on "Obscured Regions in the Greenwich Astrographic Zone" and on "Obscuration around the North Pole," have been published in the *Monthly Notices*.

The Sun was photographed at Greenwich on 263 days. 24 zero photographs were obtained and 30 sets of visual observations for zero of position-angle. The Greenwich plates have been measured up to 1941 June 16.

Up to the end of 1942 October 31 there is one day unrepresented in the combined Greenwich, Cape and Kodaikanal series for 1942.

A series of 6 photographs at short intervals was taken just after the beginning of the partial solar eclipse on 1942 September 10, to enable the time of first contact to be determined. The deduced time was $15^h\ 24^m\ 14^s.69 \pm 0^s.37$ U.T.

Observations in *Hα*, chiefly for the detection of bright chromospheric eruptions, were made on 178 days: observations on 42 of these days were of less than 15 minutes' duration. 80 measures of radial velocities of dark markings were made, of which 69 were close to sunspots. There were three measured radial velocities > 100 km./sec. 21 bright eruptions were observed, of which two were of major importance. One of these, on March 3, had a peak intensity greater than twice the intensity of the continuous spectrum 15 A. from the centre of *Hα*.

A paper has been published during the year in *Monthly Notices* on "Characteristic Radial Motions of *Hα* Absorption Markings seen with Bright Eruptions on the Sun's Disk."

Two Time Service stations have continued in regular operation throughout the year. 165 determinations of time were made at Station A and 157 determinations were made at Station B. Experience in the operation of the two stations has been of great value, and the installation of a direct land-line link between them has still further extended the advantages of the system. One of the features of the arrangement has been the more accurate assessment of the precision of the time signals; when signals were checked back only against the clocks from which they had originated, effects of clock erratics were masked, giving rise to a spurious estimate of performance. Signal transmission and reception during the past year has been based on clocks at both stations and on the quartz clocks at the National Physical Laboratory and the Post Office Radio Department.

The steady progress which has been made in the improvement of the service has been accelerated by the increased use of quartz clocks. It has become apparent that free pendulum clocks of the type at present employed are not capable of giving the precision demanded. The accumulated data on pendulum clocks is, however, being utilised in the development work now in hand. It is possible that with certain modifications pendulum clocks may, at some future date, give valuable data to supplement quartz clocks in the maintenance of the National Time Service. A number of pendulum clocks are, of necessity, still used for interpolation, but only because of the unavoidable delay in obtaining further quartz-controlled frequency clocks.

Probably the least satisfactory link at the moment is in the astronomical observations. The standard type of transit instrument with an impersonal micrometer for visual operation appears to be subject to certain systematic and quasi-systematic errors which, according to information from the U.S. Naval Observatory, are not so troublesome with an instrument of the photographic zenith tube type. The accidental errors of observations with the photographic instrument are also appreciably smaller than those of visual observations. The installation at a future date of a photographic instrument is under consideration.

Further improvement has been effected in the manner of utilising the equipment and data available, with consequent increase in precision both in the time signals as transmitted and in the published definitive corrections.

Nautical Almanac Office.—The work of the Office has been continued without sensible modification.

During the year the following publications were issued:—

Nautical Almanac, 1943	March.
Abridged Nautical Almanac, 1943	March.
Apparent Places of Fundamental Stars, 1943	September.
Air Almanac, 3rd and 4th Quarter, 1942	About 6 months in advance.
1st and 2nd parts, 1943	

The only important change in the *Nautical Almanac* has been the omission of the Occultation Reduction Elements, which have not been computed. The programme of occultation prediction has been continued in its modified form and predictions sent to all stations with which communication is possible.

The apparent places for 1943 of the 426 10-day stars normally received from the Office of the Connaissance des Temps for inclusion in the volume of *Apparent Places of Fundamental Stars* were computed in the Office, while the 32 circumpolar stars were received from Washington.

For 1943, the *Air Almanac* was issued in four-monthly parts instead of quarterly. During the year the *Almanac* has been redesigned, with a larger page size to allow for the tabulation of the data for all bodies at a uniform interval of 10^m.

The facilities of the Office for general computational work have been utilised to an increasing extent during the year, and the astronomical work has been restricted to that necessary for the preparation and publication of the various *Almanacs*.

Royal Observatory, Edinburgh
(*Director, Professor W. M. H. Greaves, Astronomer Royal for Scotland*)

Owing to the transfer of the services of members of the staff to another Department most of the normal activities of the observatory have now ceased. It has been found possible to maintain the seismological and meteorological services and also the daily reception of the Rugby 10^h signals against the free pendulum clock Shortt No. 4. The measurements of the reception times are forwarded to the Royal Observatory, Greenwich, and are utilised for the inclusion of Shortt No. 4 in the Greenwich "Mean Clock."

The equatorials are on a care and maintenance basis and are in good condition.

Royal Observatory, Cape of Good Hope
(*Director, Dr. J. Jackson, F.R.S., H.M. Astronomer*)

There has been a further release of the staff for purposes connected with the war, but the essential services have been carried on. The measurement of photographic plates for the zone $-52°$ to $-56°$ has been given up for the present.

The programme with the Reversible Transit Circle included the observation of Backlund-Hough stars south of declination $+35°$. During the year 1942, 7431 transits were observed. These included 160 of the Sun, 46 of the Moon, 87 of Mercury, 111 of Venus, and a few of each of the major planets and three of the four large minor planets. The reductions are well advanced.

With the Victoria Telescope 2406 plates were taken on 218 nights. 2266 plates were measured and the parallaxes of 75 stars were determined. All stars south of the equator with a parallax greater than $0''{\cdot}100$ have been replaced on the observing list. Such stars are important not only because their distances can be determined with the greatest accuracy but because any irregularity in their motion will be detected more easily than for more distant stars. Even a few scattered observations of such stars may prove useful in the future.

The photometric work, both visual and photographic, has been continued. The Schilt photometer, after being modified, has worked well throughout the year and 30,274 images were measured. Of these, 7819 were on grating plates of the zone $-30°$ to $-35°$, 17,889 on plates comparing the zone with the standard E regions in $-45°$ and 354 for the magnitudes of comparison stars for Nova Puppis (1942). A considerable amount of time was devoted to examining the relation between our system of magnitudes and the International System. Results derived from the Harvard magnitudes and from the Hyades and Pleiades do not agree very well.

A series of spectrum plates centred on declination $-32°{\cdot}5$ is being taken by Dr. J. S. Paraskévopoulos of the Boyden Station of the Harvard Observatory at Bloemfontein. The purpose is to supply spectra for stars in the zone $-30°$ to $-35°$ not included in the Henry Draper Catalogue, but for which positions and proper motions are being determined in our zone work. Professor Cillié of Stellenbosch has started the classification of the spectra. He expects to supply about half of the missing spectral types: the difficulty in supplying the others is mostly due to the fact that they are photographically faint although bright enough to have been observed visually with meridian instruments.

As it was unlikely that the minor planet Eros would be well observed elsewhere in 1942, an effort was made to observe it as often as possible. It proved to be rather faint, and difficult to observe with long exposures on account of its motion. However, it is shown on plates taken on 22 nights between June 28 and October 2, mostly in August and September. The plates taken with the Astrographic Telescope have generally four exposures, two taken with the telescope west of the pier and two with the telescope

east. Plates were also taken on 17 nights with the Victoria Telescope. These plates should be useful for determining the solar parallax by the gravitational method.

During the year 47 observations of 32 occultations were made. They indicate a mean correction to the tabular longitude of the Moon of $+0''.29$. This error has decreased steadily in recent years and should vanish in 1943.

The Sun was photographed on 322 days. Of the 43 days missed, 19 were in May and June. All the plates taken since the commencement of the war have been stored at the observatory. The photoheliograph was thoroughly cleaned and overhauled and new arrangements made for exposing so as to avoid shake inherent in the rather light mounting of the instrument.

Comet Whipple 1942 *a* was photographed on 14 nights from February 16 to June 6. The plates have been measured and the results sent to La Plata Observatory where Mr. Gualberto M. Iannini plans to compute a definitive orbit. Mr. R. de Kock made 2773 observations of 101 long-period variable stars and Mr. W. P. Hirst continued his observations of double stars with the 7-inch refractor.

Armagh Observatory
(*Director, Dr. E. M. Lindsay*)

Research has been greatly interrupted owing to other activities and it is only now that the star-counts of part of the Southern Milky Way are ready for publication.

Miss Meredith, who was appointed to the newly established Research Studentship and who has been working on the Coal Sack, resigned to take up other duties. It is hoped that this work can be completed during the year but the Director spends much time away from the observatory on other duties.

The normal University Teaching and the meteorological work have been continued without interruption.

Cambridge Observatory
(*Director, Sir A. S. Eddington, O.M., F.R.S.*)

In the last report reference was made to a new photoelectric photometer constructed for use on magnitude determinations with the Sheepshanks telescope. Through various difficulties and delays this could not be brought into regular operation until near the end of the year. The amplifier had to be re-designed, because in present conditions it is impossible to procure a pair of triode valves sufficiently well-matched to be used with the original bridge circuit. A single-valve circuit is now employed for the amplification; and the photometer in its present state is similar to the one designed and used by Dr. Brück for the study of the solar spectrum, except that a higher grid-leak resistance and a more sensitive galvanometer are employed. The potassium vacuum cell originally used has been replaced by a gas-filled cell of the same type. The performance and stability are found to be as good as those of the solar instrument. The sensitivity is such as to give a galvanometer deflection of 15 cm. for a star of magnitude 6·0 and type G5; this represents a gain of about $1\frac{1}{2}$ magnitudes as compared with the stellar photometer previously used.

Solar Physics Observatory, Cambridge University
(*Deputy Director, Mr. W. Moss*)

From January till May routine work with the spectroheliograph was continued. A series of photographs of an eruption was made on April 11. At the end of May the instrument was re-arranged for simultaneous exposures of hydrogen $H\alpha$ and helium D_3 with a view to comparing the structure of prominences photographed in the light of

these two lines. In addition to similar material obtained with the Rowland concave grating, sets of such spectra of different parts of prominences have been secured with the spectroheliograph for measurement on the photometer. An attempt has also been made to obtain complete spectroheliograms of prominences in $H\alpha$ and D_3.

The spectrohelioscope has been mainly used in collaboration with the spectroheliograph programme. A simple lamp photometer has been attached to the spectrohelioscope in order to improve the arrangements for photometric observations with this instrument.

Work on the solar spectrum with the photoelectric photometer attached to the McClean solar telescope has been continued, and more photometric records of the solar spectrum have been secured.

Earlier studies of the spectra of Nova Lacertæ and β Lyræ have been practically completed.

University Observatory, Glasgow
(Director, Professor W. M. Smart)

The preliminary work on the analysis of the proper motions of the *General Catalogue* mentioned in the last report has been continued, but progress has been somewhat slow.

Courses in Nautical Astronomy were arranged for R.A.F. Cadets who had been sent to the University for a general scientific training.

University of London Observatory, Mill Hill
(Director, Mr. C. C. L. Gregory, Wilson Observer)

The observatory remained closed during the year, the 24-inch Grubb photographic refractor being still dismantled. Spectra of γ Cassiopeiæ were, however, obtained on 14 nights, and these showed that the typical double emission lines of hydrogen, superimposed on a broad absorption background, had again become visible.

Norman Lockyer Observatory, Sidmouth
(Director, Mr. D. L. Edwards)

Work on the galactic clusters has been continued, and the survey mentioned in the last report has now dealt with 24 clusters, the results for 13 of which have already been published. These results include data on star counts, magnitudes, colour indices, cluster diameters, distances and characteristics as well as interstellar absorption. Some papers on questions relevant to this survey have also been published.

Observations of γ Cassiopeiæ have been continued, since spectrum changes, though slighter and less rapid than formerly, are still noticeable. In addition to the spectrum observations, determinations of magnitudes and colour indices have been made, as well as of colour temperatures from relative gradients of γ and δ Cass. Results for the magnitude and CI observations have already been published.

The law relating stellar magnitudes and image diameters on a photographic plate has been investigated, and a new formula suggested which is applicable to bright stars. It also takes into account a colour effect which was discovered during the investigation, and which becomes very appreciable for images of large diameter.

The star XZ Aurigæ has been observed at intervals, in order to follow any possible changes in photovisual magnitude, and a few plates were also taken of Nova Cygni (1942) for magnitude determinations. Results for the latter were published in *Nature*, **150**, 463 (1942). The 12-inch "McClean" instrument has been used mainly for colour temperature observations (including γ Cass, mentioned above) and routine spectrum plates of Be stars for a spectrophotometric survey of these objects.

University Observatory, St. Andrews
(Director, Professor E. Finlay Freundlich)

The equipment of the observatory, built during the first year of the war, is not yet completed.

During the last year the transit instrument was mounted and the two Synchronome clocks set into operation.

No regular observations are being made on account of the war.

Stonyhurst College Observatory, Blackburn
(Director, Rev. J. P. Rowland, S.J.)

The staff remains as last year. The only astronomical work carried out was the routine observation of the Sun. Drawings were obtained on 225 days and show that the number of new groups which appeared during the year was 121, as against 195 in the previous year, with a mean daily area, in units 1/5000 of the disc, of 1·88 as against 3·12 in 1941.

Helwan Observatory
(Director, Dr. M. R. Madwar)

Time-Service.—The time-service was maintained as usual, the error of the standard sidereal clock Shortt No. 1 being determined from star transits. The number of transits taken through the year amounted to 57.

Rhythmic W/T signals were received daily from Bordeaux and Rugby. The old clock switch-board was replaced by a new one, and on account of the difficulty in obtaining dry cells the electric supply for the running of the clocks was taken from an accumulator charged automatically from the mains.

Occultations.—Observations on lunar occultations were continued. The number of observations during the year amounted to 31.

The Reynolds' reflector is still dismounted and the optical parts stored away in a safe place, as a precaution against air raids.

General.—Magnetic, seismological, meteorological and solar radiation observations were continued as usual.

Union Observatory, Johannesburg
(Union Astronomer, Dr. W. H. van den Bos)

26½-Inch Visual Refractor.—153 micrometrical measures of double stars have been made.

Occultations of Stars by the Moon.—61 observations were obtained.

Franklin-Adams Star Camera.—Plates taken with this instrument were distributed as follows:—

Variable Star Regions	190 plates
Minor Planet Regions	249 ,,
Comets	14 ,,
Total	453 plates

Staff.—No staff changes took place during the year.

Mr. Finsen devoted the greater part of his time to research on problems connected with the war effort.

Dr. H. van Gent worked at the observatory throughout the year.

Radcliffe Observatory, Pretoria
(*Director, Dr. H. Knox-Shaw, Radcliffe Observer*)

Dr. Redman has continued the measurement of the 1940 eclipse spectra, concentrating his attention on the spectrum of the solar disk immediately within the limb. A method has been developed for separating the disk spectrum from the mixture of disk and chromosphere actually photographed, and it has been found that at about 1″ within the limb there is a Fraunhofer spectrum with practically no emission lines. In comparison with the centre of the disk strong lines are weakened; weak lines have the same, or slightly greater, equivalent width. These measures, for which $\cos\theta = 0{\cdot}05$ approximately, furnish a powerful criterion for determining what values the parameters of standard Fraunhofer line theory may take.

Dr. Zanstra resigned the Radcliffe Travelling Fellowship in Astronomy at the end of February on his appointment to a lectureship in physics at the University College of Natal.

The Director completed the reduction of Mr. Williams's photometric observations of early type stars and communicated to the Society a paper embodying the results. He also finished a card catalogue of 2766 O- and B-type stars in the southern hemisphere and has been attempting a re-reduction of the Harvard southern photometry. He observed 75 occultations during the year and reduced these and 91 observed in former years, the results being communicated to Professor Brouwer.

There is no progress to report on the 74-inch mirror or on the spectrograph.

Kodaikanal Observatory, Madras
(*Director, Dr. A. L. Narayan*)

The routine observational and research work has been carried on as usual, though most of the permanent members of the staff have been called away for war work.

The photoelectric spectrophotometer mentioned in last year's report is now in efficient working order. The work on intensities and contours of the Fraunhofer lines in the solar spectrum with this instrument has been continued by the Director.

From a study of coincidences of lines in the two strong bands (8, 27) and (9, 28) of phosphorus with solar lines having intensities 0 and less, it is concluded by K. N. Rao that the molecule of phosphorus exists in the solar atmosphere.

A statistical study of Doppler displacements observed at the spectrohelioscope from 1935 to 1942 by C. K. Ananthasubrahmanyam has revealed a maximum frequency of displacements at 36 km./sec. in prominences and *Hα* dark markings, irrespective of their association with sunspots.

The publication of *Kodaikanal Observatory Bulletins* and *Annual Reports* has been suspended for the duration of war on account of paper shortage.

Six papers were contributed by the staff during the year.

Commonwealth Solar Observatory, Canberra
(*Director, Dr. R. v. d. R. Woolley*)

The astronomical activities of the observatory were in abeyance during 1942 except that towards the end of the year regular sunspot sketches and spectrohelioscope surveys were commenced.

Melbourne Observatory
(*Director, Dr. J. M. Baldwin, Government Astronomer*)

Owing to absence on war work of two members of the professional staff, and to the death of a third, astronomical work is now confined to time-service. Occultations were observed in 1940, but observations had to be discontinued thereafter. When possible, attention has been given to the revision of manuscript and its preparation for printing at a later date.

Sydney Observatory
(*Acting Government Astronomer, Mr. H. W. Wood*)

During the year Volumes 23 and 24 of the Sydney Section of the *Astrographic Catalogue* have been printed and distributed, and measures of plates and preparation of manuscript continued. There are now four volumes ready for the printer and a number in an advanced stage.

The occultations predicted in the *Nautical Almanac* have been observed when possible; those for 1941 having been reduced and published in the *Monthly Notices*, and the occultations observed during 1942 are now being reduced. Reductions have been carried out in duplicate on the Occultation Cards, one set being forwarded to Yale Observatory.

A programme for the observation of double stars with the 11½-inch telescope has been drawn up and a beginning made with the work. The announcement of the discovery of Nova Puppis 1942 was received on November 13 and observations have been made of its position, spectrum and magnitude.

The civil work of the observatory has been continued, though somewhat reduced, and lectures on astronomy have been delivered regularly. During the year there were about 800 visitors who were shown the uses of the various instruments and on fine nights were given the opportunity to look through the telescope. Two editions of a booklet, "Elementary Astronomy for Service Use," were prepared and distributed.

Dominion Observatory, Wellington, New Zealand
(*Acting Director, Mr. R. C. Hayes*)

Free Pendulum.—The performance of the free pendulum was disturbed rather frequently by local earthquakes. Investigation has shown that marked changes of rate which occur from time to time can be associated with one or other of the following causes: (1) Violent fluctuations in barometric pressure; (2) Changes in the direction of local ground tilt; (3) Local earthquakes.

Novæ Puppis 1942.—This observatory assisted in the matter of issuing prompt notice of the Nova observed in Puppis by Mr. A. G. C. Crust on the evening of 1942 November 10.

Mr. Robert Barker's Observatory, Cheshunt, Hertfordshire

Seeing conditions were below the average during 1942, and critical lunar and planetary observations were necessarily limited.

New clefts in and around Pitatus (one cleft over 200 miles in length) were detected and plotted. The commencement, development and extension of the five dark radial bands of Aristarchus, first seen here twelve years ago, have been confirmed by recent photographs at Mount Wilson. A delicate dusky streak on the inner edge of Saturn's Ring B, first seen by W. Haas (U.S.A.) was confirmed.

Mr. J. Evershed's Observatory, Ewhurst, Surrey

Routine work with the spectroheliograph has been discontinued, and the instrument used only for recording interesting phenomena on the Sun's disk and limb, and for visual observations. The last and final batch of spectroheliograms was sent to Kodaikanal in September.

The liquid prism spectrograph has been adapted for the special work of recording details of the magnetic fields in the umbræ and penumbræ of sunspots. A novelty in this instrument is the 4-inch aperture reflecting prism constructed of plywood by Mr. Hargreaves, which by the application of lac resin is rendered impervious to the refracting liquid. In this design both the reflecting and transmitting plates are so mounted as to be absolutely free from distorting strains.

Dr. J. L. Haughton's Observatory, Teddington, Middlesex

The optical parts of the observatory were removed from their place of safety and remounted in the observatory early in the summer. Efforts were made to continue the lunar occultation programme, but pressure of work, combined with bad weather, prevented any observations from being made. Lectures were given, and the observatory was opened to members of the A.T.C. on several occasions.

Mr. M. B. B. Heath's Observatory, Kingsteignton, Devon

Daylight observations of Mercury were made on 24 days and 6 drawings were made. Venus was similarly observed on 24 days. Among other occasional phenomena the partial eclipse of the Sun on September 10 (measured local magnitude 0·30) was observed. One observation was made of Nova Puppis.

Mr. F. M. Holborn's Observatory, Streatham, London

Variable star observations with the $3\frac{1}{4}$-inch refractor were recommenced in December, records being sent to the British Astronomical Association. The $8\frac{1}{2}$-inch reflector was remounted ready for the 1943 programme.

Mr. A. M. Newbegin's Observatory, Worthing, Sussex

Observations of the Sun were resumed on 1942 May 15 after a lapse of two years due to enforced absence from home arising out of the war.

At the end of the year 80 observations for prominences, sunspots and hydrogen disk markings had been made. The mean daily frequency for prominences was 6·78, and for sunspots 1·73. Bright *Hα* eruptions were recorded on 42 days, only one of which attained an intensity of 3. This occurred over a group of sunspots on July 8, and an account of the disturbance was published in the *B.A.A. Journal*, Vol. **52**, No. 8.

A complete list of bright eruptions has been sent to the Royal Observatory, Greenwich, for inclusion in the *Bulletin for Character Figures of Solar Phenomena*, issued by the International Astronomical Union.

Mr. B. M. Peek's Observatory, Solihull, Birmingham

Observational work has been almost entirely confined to the study of the surface features of the planet Jupiter. In addition, fourteen occultations of stars by the Moon were recorded in 1942 and a few estimates made of the magnitude of Nova Persei 1901.

A considerable amount of time has been given to the preparation of the Thirty-first Report of the Jupiter Section of the British Astronomical Association from the extensive observational material submitted by members of the Section. This Report covers the apparitions of 1937, 1938 and 1939–40 and has recently been published by the Association —*B.A.A. Memoirs*, Vol. **35**, Part I.

Mr. F. J. Sellers's Observatory, Muswell Hill, London

This observatory remained closed during 1942, but it is hoped that it will be possible to resume observations in the near future. In the meantime the Director has compiled quarterly solar summaries, published in the *B.A.A. Journal*, from records by other members of the Solar Section.

REPORTS ON THE PROGRESS OF ASTRONOMY

COMETARY SPECTRA

For many years the only molecules identified in comets have been *CN*, C_2, *CH*, CO^+ and N_2^+: *CN*, C_2 and *CH* belong mainly to the head of the comets, whereas CO^+ and N_2^+ are characteristic of the tail. In the last three years four additional molecules have been shown to be present in the head, three of them diatomic (*OH*, *NH*, CH^+), and one triatomic (CH_2); it is also highly probable that OH^+ and NH_2 are present. These additions result from improved observations, especially in the ultraviolet region, and from recent laboratory work. Only a very few weak emission features remain unidentified in the region $\lambda < 4800$ A., but there are still a number of fairly strong unexplained emissions in the visual region, some of which are being tentatively attributed to NH_2.

Most cometary bands display rotational structures which depart considerably from the rotational intensity distributions of molecular bands as obtained from sources in the laboratory, even at low temperatures. These departures have been successfully attributed to the mechanism of excitation by solar light, account being taken of the presence of Fraunhofer lines. On the basis of these new data, interesting conclusions can be reached on certain general problems of cometary physics, although many major questions remain open. The present review discusses the progress made during the last three years in the spectra of the heads of comets. No important spectroscopic contribution has been made to the problem of the tails, except the presence of CH^+ which will be mentioned later on.

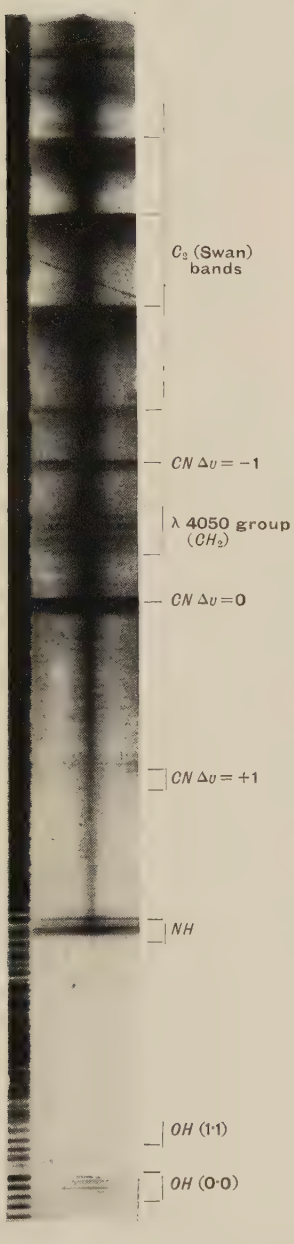
1. *New Observations and Identifications in the Ultraviolet Region* (1)

Up to 1940 the cometary emissions in the ultraviolet region, $\lambda < 3500$ A., had been photographed only with spectrographs of very low resolving power, and no reliable identification could be based on these observations. Since 1940 the ultraviolet spectra of many comets have been obtained at the McDonald Observatory with two quartz slit spectrographs having the respective dispersions 137 and 69 A./mm. at λ 3360. This material has revealed the presence in most comets of two fairly strong groups of lines: one near λ 3090 due to *OH*, the other near λ 3360 due to *NH*. Moreover, fainter lines due to *OH* (possibly with a weak contribution of *CH*), appear near λ 3140 (six lines of the 1, 1 transition of *OH*) and λ 3204 (two lines of the 2, 2 transition). In the region of longer wave-lengths, the $\Delta v = +1$ sequence of *CN* gives a characteristic group near λ 3570, which group very probably contains a contribution from OH^+. These features are shown on Plate 2.

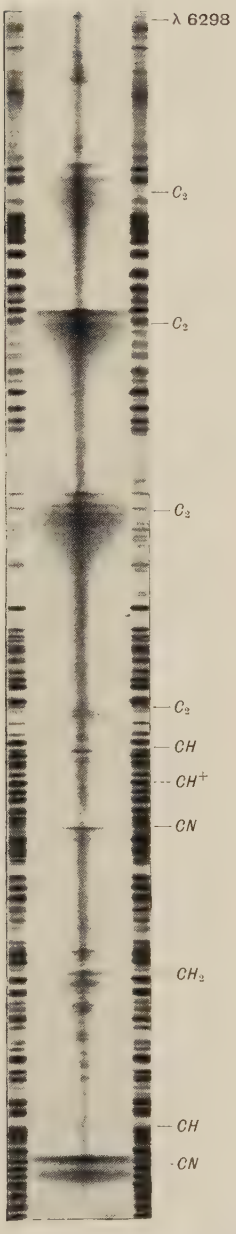
OH-lines.—The (0, 0) band of the $^2\Sigma^+ \rightarrow {}^2\Pi_{\text{inv}}$ system of *OH* consists of several sharp lines in the region $\lambda\lambda$ 3078–3100; the wave-lengths as measured in Comets 1940 *c* (Cunningham), 1941 *d* (van Gent) and 1942 *a* (Whipple) are given in Table I. It appears from this table that the relative intensities of the *OH* lines vary appreciably from comet to comet (see section 4).

The *R* branches are absent, except for the first lines $R_2(\frac{1}{2})$ and $R_2(1\frac{1}{2})$ at λ 3084·03 and λ 3080·22 which, on microphotometer tracings, appear in the violet wings of $P_1(2\frac{1}{2})$ at λ 3086·3 and $P_1(1\frac{1}{2})$ at λ 3081·6.

The six faint lines observed in comet 1940 *c* between λ 3134·5 and λ 3152·4 (Plate 2) belong to the (1, 1) band of *OH*, and possibly to the (0, 0) Fortrat band of $CH(c^2\Sigma^- \rightarrow x^2\Pi)$.



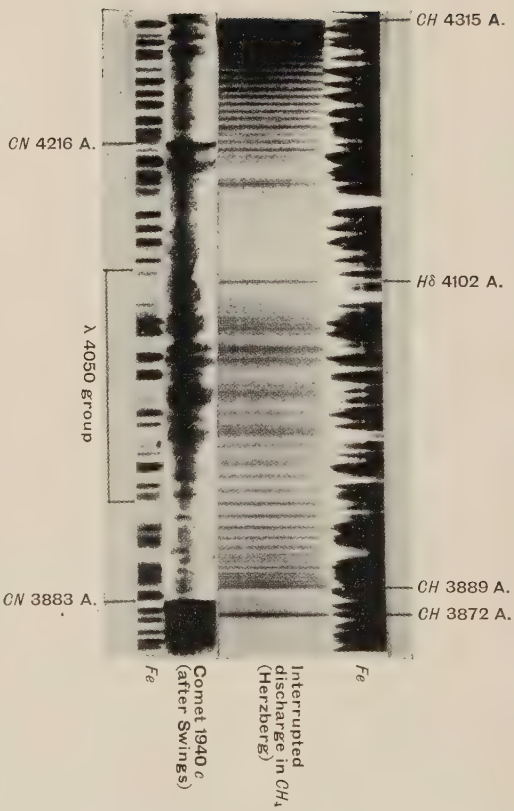
Spectrum of Comet Cunningham (1940 *c*) in the region λ 3000–λ 6300.



Spectrum of Comet Cunningham (1940 *c*) in the region λ 3850–λ 6300.

P. Swings, Cometary Spectra.

Spectrum of Comet 1942 a (Whipple) in the region λ 3850–λ 5700, on a perfectly moonless night.



Identification of CH_2 in Comet Spectra.

TABLE I

(0, 0) *Band of OH in Comets* 1940 *c*, 1941 *d*, *and* 1942 *a*

1940 *c*		1941 *d*		1942 *a*		λ Lab.	Notation
2	3078·5	1–0	79·0	1–0	78·7	78·43	$Q_1(1\frac{1}{2})$
1	3081·6	3	81·7	4	81·9	81·64	$P_1(1\frac{1}{2})$
2	3086·3	...	...	1–2	86·3	86·38	$P_1(2\frac{1}{2})$
4	3090·3	1	90·2	0	89·7	90·46	$Q_2(\frac{1}{2})$
						89·84	$Q_2(1\frac{1}{2})$
						89·84	$Q_2(2\frac{1}{2})$
1	3093·7	2	93·6	2	93·9	93·72	$P_2(1\frac{1}{2})$
3	3096·4	...	...	...	...	96·34	$P_2(2\frac{1}{2})$
2	3099·4	...	...	0	99·4	99·57	$P_2(3\frac{1}{2})$

NH lines.—The (0, 0) band of the $^3\Pi \rightarrow {}^3\Sigma$ system of *NH* consists of a group of seven strong lines near λ 3360. Their wave-lengths are listed in Table II.

TABLE II

(0, 0) *Band of NH in Comet Cunningham* ($^3\Pi \rightarrow {}^3\Sigma$)

Comet	Laboratory	Notation	Comet	Laboratory	Notation
3350·8 (2)	50·8	$R_2(1)$	3361·5 (2)	61·73	$Q_1(1)$
3354·1 (4)	53·92	$R_2(0)$		61·0	$Q_1(2)$
	53·64	$R_1(1)$	3364·7 (2)	64·0	$P_2(2)$
3357·9 (8)	57·83	$R_1(0)$	3369·1 (3)	69·1	$P_1(2)$
	57·8	$Q_2(2)$	3372·0 (1)	72·1	$P_1(3)$

Region λλ 3560–3600.—A group of lines observed around λ 3570 presents a complex problem. There is no doubt that the major part of the emission belongs to the $\Delta v = +1$ sequence of *CN*; yet certain features are certainly not attributable to *CN*. The (0, 0) band of $OH^+(^3\Pi \rightarrow {}^3\Sigma)$ falls in the same region, and so does the (8, 0) band of CO^+. The lines measured around λ 3570 in the spectrum of comet 1940 *c* are listed in Table III with their identifications.

TABLE III

Lines Observed in Comet 1940 *c between* λ 3560 *and* λ 3600

Comet		Element	Identification *	
			Notation	
λ	Int.		Vibrational	Rotational
3565	1–0	? OH^+	(0, 0)	R_3 †
3572·2	2	*CN*	(1, 0)	$R(14)$ ‡
		CN	(2, 1)	$R(5)$ ‡
		OH^+	(0, 0)	$Q_3(1)+Q_3(2)$
3577·3	1–2	*CN* §	(1, 0)	$R(5)$ ‡
		CN §	(2, 1)	$P(5)$ ‡
3584·3	2–3*n* ‖	*CN*	(1, 0)	$P(2)$–$P(14)$
3589·4	1–0	CO^+ §	(8, 0)	...
3597·4	1–2 ¶	CO^+ §	(8, 0)	...

* Contributions by the bands of *NO* (β system), N_2 (second positive system), N^+ (first negative system), and C_2 (Deslandres–D'Azambuja system) that fall in this region may be disregarded.

† $R_3(1)$, $R_3(2)$, $R_3(3)$, $R_3(4)$.

‡ Blend of lines around this transition.

§ Minor contribution of OH^+ not excluded.

‖ Extending from λ 3581·4 to λ 3586·3.

¶ Possibly double at λ 3595·7 and λ 3598·6.

As is apparent from this table, the situation is rather confused. This is mainly because the McDonald Observatory spectrograms, which have the correct exposure around λ 3570, have a dispersion of only 175 A./mm. and an effective slit width of 2·5 A. in this region. The line λ 3572·2 is definitely too strong to be due only to $R(14)$ of (1, 0) and $R(5)$ of (2, 1), and a contribution by OH^+ is very likely. As for λ 3565, it does not seem possible to attribute it to $R(17)$ of the (2, 1) band of *CN*, and it is more probably due to the first lines of the R_3 branch of OH^+.

The lines λ 3589 and λ 3597 were enhanced on the spectrogram of Comet Cunningham, taken on 1941 December 28, on which the tail spectrum was well apparent; this exposure is the only one obtained of Comet Cunningham at the McDonald Observatory, showing all the strong bands of CO^+ and N_2^+. It is thus safe to attribute λ 3589 and λ 3597 mainly to the (8, 0) band of CO^+, which has a laboratory intensity of 6 on a scale of 1–10; but OH^+ may be a contributor to these features.

Summarizing the present situation, we may say that there is a strong suspicion that the (0, 0) band of OH^+ is present in cometary spectra. The fainter (1, 0), (0, 1) and (1, 1) bands near $\lambda\lambda$ 3332, 3893 and 3695, respectively, have not been observed in comets. It is desirable to have observations of cometary spectra in the region around λ 3570 with a higher resolving power.

2. *New Observations and Identifications in the Photographic Region*

Cyanogen bands.—The four sequences $\Delta v = 1$, 0, −1 and −2 of the violet system $^2\Sigma^+ \rightarrow {}^2\Sigma^+$ have been observed and described on many occasions. Special emphasis

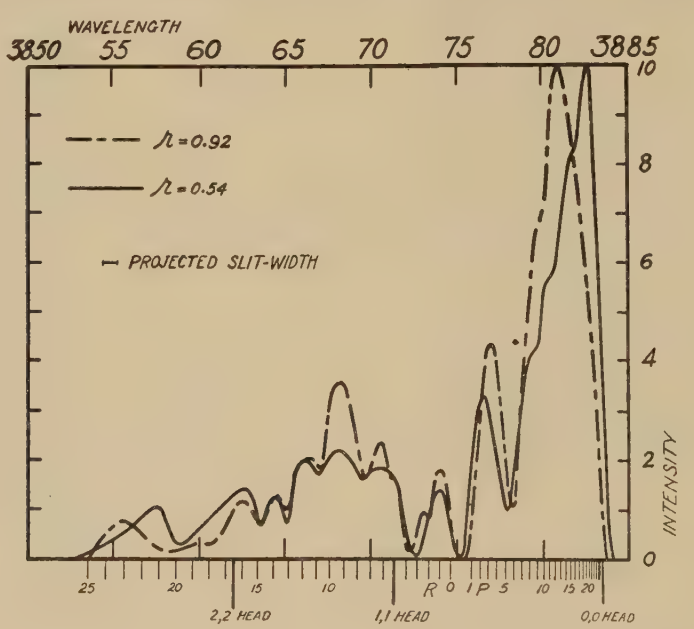


FIG. 1.—*Observed CN band profiles, Comet* 1940 *c*, $r = 0{\cdot}54$ *and* 0·92.

has been placed in recent years on the intensity distributions, which differ considerably from the laboratory intensity distributions even at low temperatures. Instead of having a smooth profile, as is usually found in the laboratory sources, the *CN* bands of comets present complex structures with fairly sharp maxima and minima. Such structures have been observed in all sequences whenever the resolving power of the spectrograph was high enough (2). Fig. 1 gives the profile of the $\Delta v = 0$ sequence as observed by McKellar in Comet Cunningham. The most striking feature, which is also apparent

on Plates 3 and 4, consists in two maxima near $P(3)$ and $R(1)$, followed by deep minima around $P(5)$ and $R(3)$. For comets 1941 *e* (3) (Paraskevopoulos-de Kock), 1942 *a* (4) (Whipple 1) and 1942 *f* (5) (Whipple 2), spectrograms of effective slit width 0·7 A. reveal some structure in the maxima near $P(3)$ and $R(1)$; this structure corresponds to two or three *CN*-components arising from $K' = 2$ and 3 (and possibly 1). A still better resolution (dispersion 57 A./mm. and projected slit width 0·5 A.) has been used by McKellar (6) on Comet Whipple 2; his spectrogram shows the resolution of the R branch-lines. The intense maximum near the (0, 0) head may be double, as in 1941 *c*: a first maximum is present at $P(11)$, λ 3880·3, the emission extending from $P(8)$ to $P(13)$, and a second maximum is observed at $P(15)$, λ 3881·7, the emission covering the interval $P(13)$ to $P(19)$. The other bands, especially the (0, 1) transition, reveal similarly complex structures (2).

The structures of the *CN* bands vary from comet to comet (2) and may even vary appreciably in a given comet (2, 7): this problem will be discussed extensively in section 4.

The so-called "tail bands" of *CN* belong to the same system, $^2\Sigma^+ \rightarrow {}^2\Sigma^+$, but arise from higher vibrational levels. They are absent in comets.

As for the red system of *CN*, ($^2\Pi \rightarrow {}^2\Sigma$), the observational material is still rather scanty; yet it may be said definitely that in the spectral region $\lambda < 6600$ A. the red system of *CN*, if present at all, is extremely weak. The only fairly good coincidence is that of a cometary line near λ 6333 with the strong (4, 1) band of the red system of *CN*.

Bands of CH.—The (0, 0) band of the $B^2\Sigma^- \rightarrow x^2\Pi$ system near λ 3900 is represented by a number of lines concentrated very close to the nucleus of the comet. All the lines observed in Comet 1940 *c* between λ 3886 and λ 3922 belong to *CH*; they are listed in Table IV.

TABLE IV

(0, 0) *Band of* $B^2\Sigma^- \rightarrow x^2\Pi$ *of CH in Comet* 1940 *c*

Comet		Lab.	Designation		Comet		Lab.	Designation	
λ	Int.	λ	Branch	K*	λ	Int.	λ	Branch	K*
3886·6	0	86·4	Q_2	1	3897·2	1–2	97·5	P_1	2
3890·0	1–2*n*	89·1	Q_1	1			96·5	P_2	2
		89·8	Q_1	2	3902·6	1–2	02·6	P_1	3
		88·9	Q_2	2			02·0	P_2	3
		91·2	Q_1	3	3908·3	1–2	08·3	P_1	4
		90·5	Q_2	3			07·8	P_2	4
		91·1	P_2	1	3914·5	1	14·4	P_1	5
		90·1	$P_{Q_{12}}$	1			14·0	P_2	5
3893·1	1	92·9	P_1	1	3921·5	1–0	21·1	P_1	6
							20·7	P_2	6

* The $\mathcal{J}''$ values are: $\mathcal{J}'' = K + \frac{1}{2}$ for P_1, Q_1, R_1; $\mathcal{J}'' = K - \frac{1}{2}$ for P_2, Q_2, R_2.

The (0, 0) band of the $A^2\Delta \rightarrow x^2\Pi$ system is represented by a number of lines, some of which are very strong at small heliocentric distances. These lines are given in Table V. All the emissions observed in Comet 1940 *c* between λ 4280 and λ 4350 are unambiguously identified with *CH*. In particular, there is no trace of a line between λ 4304 and λ 4311, which might have been attributed to the strongest lines of the $^2\Delta \rightarrow {}^2\Pi$ (0, 0) transition of carbon deuteride.

The intensity distribution amongst the *CH* lines varies appreciably with heliocentric distance (see section 4).

Bands of C_2.—The relative intensities among the Swan bands are very similar to the laboratory distribution at $T \simeq 3000°$; this behaviour, which is related to the absence of a permanent electric dipole moment, will be discussed in section 4.

TABLE V

(0, 0) *Band of* $A^2\Delta \rightarrow x^2\Pi$ *of CH in Comet* 1940 *c*

Comet		Laboratory			Comet		Laboratory		
λ	Int.	λ	Branch	K	λ	Int.	λ	Branch	K
4281	0–1	4280·1	R_1	5	4313·2	6*n*†	4312·2	Q_1	4
		4279·6	R_2	5			4312·2	Q_1	5
4285·7	1–0	4286·2	R_1	4			4311·6	Q_2	5
		4285·5	R_2	4			4311·3	Q_1	6
4291·7	1–2	4292·1	R_1	3	4329·3	1–2	4330·0	P_1	3
		4291·2	R_2	3			4328·9	P_2	3
4297·3	3*n**	4298·0	R_1	2	4334·2	1–2	4334·8	P_1	4
		4296·6	R_2	2			4333·9	P_2	4
4300·2	2–3*s*	4300·3	R_2	1	4339·0	1–0	4339·3	P_1	5
4303·9	4*s*	4303·9	R_1	1			4338·7	P_2	5
4313·2	6*n*†	4314·2	Q_1	2	4344	0–1	4343·8	P_1	6
		4313·6	Q_1	3			4343·4	P_2	6
		4312·7	Q_2	3	4348	0–1	4348·2	P_1	7
		4313·0	Q_1	4			4347·7	P_2	7

* This line is not so sharp as the following one, λ 4300.
† Extending from λ 4311 to λ 4315.

The Swan bands are the only transitions of C_2 in the observable region which involve the ground electronic level $A^3\Pi$. A further series of bands, often called the "high-pressure bands" or "Fowler's bands," was attributed until recently to another electronic transition involving the ground level $A^3\Pi$. G. Herzberg (8), however, has shown that they are simply Swan bands with $v' = 6$. The selective excitation of the one vibrational level $v' = 6$ would be due, according to Herzberg, to the fact that C_2 molecules in this state are formed by the recombination of two C atoms in a three-body collision, the heat of dissociation of C_2 being transformed into energy of excitation of C_2. Such a process is hardly to be expected in a cometary head. A fairly strong band has often been measured at λ 5428, and sometimes attributed to one of "Fowler's bands," but this identification is not correct.

The five sequences $\Delta v = -2$, -1, 0, $+1$, $+2$ are observed in comets. In the $\Delta v = -1$ sequence the first four bands are very strong (successive intensities 9, 10, 8, 6) and the fifth at λ 5473 (4, 5) is extremely weak. Then come two more fairly strong bands, with maxima at λ 5445 (int. 4) and λ 5428 (int. 4). The latter coincides with the (5, 6) band of C_2 ("Fowler's band," see above), but is too strong to be due entirely to C_2. No satisfactory identification can be found for λ 5445. There is no trace of an absorption band at λ 5427 or λ 5445 in carbon stars, where the first four C_2 bands of the $\Delta v = -1$ sequence are strong and the fifth absent.

Isotopes in Comets.—Numerous spectroscopic investigations of the carbon stars, especially by Stanford (9), have shown that C^{13} is present in the R and N stars, giving rise to absorption bands of $C^{12}C^{13}$, $C^{13}C^{13}$ and $C^{13}N^{14}$. The determination of the relative abundances of C^{13} and C^{12} in R and N atmospheres is rather difficult; but there seems to be good evidence that the abundance ratio of C^{13} and C^{12} is sometimes higher than on the Earth, and may be different in different carbon stars. In view of the fact that the strong emission bands of the comets are the same as the intense absorption bands of the carbon stars, Bobrovnikoff (10) examined the Lick Observatory cometary spectra for evidence of bands due to $C^{12}C^{13}$. He observed a faint band at λ 4744 (11) on several spectrograms of Comet Brooks and Comet Halley. New measurements of these spectrograms by the author are in excellent agreement with Bobrovnikoff's results, and there seems to be little doubt that the band should actually be attributed to $C^{12}C^{13}$. On the other hand, the spectrograms of Comet 1940 *c* taken at the McDonald Observatory fail to reveal any trace of λ 4744, despite the fact that the ordinary Swan bands are

sometimes strongly over-exposed. Thus it seems difficult to escape the conclusion that the relative abundance of C^{13} and C^{12} may be different in various comets. In any case, as already stated by Bobrovnikoff, no comet has been observed which shows isotopic bands of intensities comparable to those in the N stars. In this connection it should be pointed out that the relative intensities of λ 4737 C^{12} C^{12} and λ 4744 C^{12} C^{13}, measured by Jenkins and A. S. King (12) in meteoritic graphic and in ordinary Acheson graphite, failed to reveal any difference between the two samples.

Besides λ 4744, Bobrovnikoff also observed a faint band at λ 4751 which is probably the (1, 0) band of C^{13} C^{13}. Moreover, Brooks's comet revealed also very faint bands measured by Wright (13) at λ 4723 and λ 4706. It is extremely probable that these two features are the (2, 1) and (3, 2) bands of C^{12} C^{13}. They cannot be accounted for as peculiar band maxima due to the distortion of the rotational intensity distribution in the C^{12} C^{12} bands. The evidence for the presence of C^{13} in comets may thus be summarized as follows:—

λ 4753: (1, 0) transition of C^{13} C^{13}.
λ 4745: (1, 0) transition of C^{12} C^{13}.
λ 4723: (2, 1) transition of C^{12} C^{13}.
λ 4706: (3, 2) transition of C^{12} C^{13}.

The bands of C^{12} C^{13} are hazy, whereas the C^{12} C^{12} bands have sharp edges: this difference of profile will be explained in section 4.

No trace of the (0, 1) band of C^{13} N^{14} has ever been detected (head at λ 4208·4, against λ 4216·0 for C^{12} N^{14}). But this may be simply because the (0, 1) band of *CN* is usually not strong, and also because the abundance ratio of C^{13} N^{14} to C^{12} N^{14} is half that of C^{13} C^{12} to C^{12} C^{12}.

A systematic search for the isotopes of other elements, especially for deuterium, failed to reveal any isotopic band on the Lick or on the McDonald cometary spectrograms. This result indicates that no spectroscopically observed comet has presented abnormally high isotopic abundances compared to the Earth.

Lines of CH^+.—Among the cometary features which were still unidentified two years ago, there is a group of three lines at $\lambda\lambda$ 4231, 4238 and 4254, appearing in the wavelength range between the $\Delta v = -1$ sequence of *CN* and the strong *CH* lines. This group deserves special attention because it extends, at least partly, into the tail. It has been measured in various comets, especially in Comet Brooks by Wright (13), in Comet Morehouse by de la Baume Pluvinel and Baldet (14) and in Comet Cunningham by the author (15). The measurements are given in Table VI, which contains also the wavelengths of unidentified features listed by Baldet (16).

TABLE VI

Group of Cometary Lines near λ 4240

Comet Brooks *		Comet Morehouse		Comet Cunningham †		Unidentified Nuclear Lines	
λ	Int.	λ	Int.	λ	Int.	λ	Int.
4230	0	...	...	4231·1	1*n* ‡	4230	1
4238·5	0	4236	3 §	4240·4	1–2*n*	4238	1
4254·5	0	4250	2 ‖	4254·3	1*n*	4255·8	2
...	...	4257	10 ‖	...	...	...	...

* Long lines, present in head and tail.

† Especially conspicuous on the spectrograms of 1940 December 27, 28 and 31 (heliocentric distances 0·65, 0·63, and 0·58); the lines extend farther from the nucleus than the *CH* bands. On the quartz spectrogram of 1940 December 28, showing the tail spectrum, the lines extend far out into the tail.

‡ Possibly double at λ 4229·1 (int. 1) and λ 4231·8 (int. 1).

§ Present in head and part of tail. ‖ Present in head and tail; main contributor, CO^+.

There is little doubt that the lines measured in Comet Morehouse at λ 4250 and λ 4257 are mostly due to a band of $^2\Pi \rightarrow {}^2\Sigma$ of CO^+ (comet-tail system), and this will apply to any line measured in the tail near λ 4254. But this is not the case in the head, when the other CO^+ bands of similar intensity are absent. In the head, the line λ 4238 cannot be attributed to the (1, 2) transition of N_2^+ ($^2\Sigma \rightarrow {}^2\Sigma$) when the (0, 0) band of N_2^+ at λ 3914 is not observed. There is a strong transition of *SiN* at λ 4239 (system $^2\Sigma \rightarrow {}^2\Sigma$, band 4, 4), but this cannot contribute appreciably to the observed feature, since the stronger band at λ 4204 is not observed.

The only satisfactory identification that suggests itself is to attribute the three lines to the (0, 0) band of CH^+ (system $^1\Pi \rightarrow {}^1\Sigma$) (17). In this case we might also expect a faint (1, 0) band to be present, since in interstellar absorption the CH^+ molecules reveal their presence by the $R(0)$ lines of the three transitions (0, 0), (1, 0) and (2, 0) (17). The unidentified cometary lines that have been observed in the region between λ 3953 and λ 3975 are listed in Table VII. We may expect that some of these lines are due to the CH_2 molecules giving rise to the "λ 4050 group." The (0, 0) band of the Baldet-Johnson system of $CO^+(B^2\Sigma \rightarrow A^2\Pi$, the lower level $A^2\Pi$ being the upper state of the comet-tail bands) does not contribute, since the other transitions (1, 0) and (0, 1) of similar intensity are absent (18).

Thus it is suggested that the features near λ 4240 and λ 3960 are due, at least partly, to CH^+, according to the identifications listed in Table VIII, where the cometary wavelengths given in the first column are average values estimated from Tables VI and VII. The CH^+ molecules are present in the head and in part of the tail.

TABLE VII

Group of Cometary Lines near λ 3960

Comet Brooks *		Comet Cunningham †		Unidentified Nuclear Features ‡	
λ	Int.	λ	Int.	λ	Int.
...	...	3954·0	1	...	...
		3960·2	1–2	...	...
3963	0	3963·5	1–2	3962·5	0
...	...	...	...	3968·4	2
3974	0	3972·7	2	3974·8	0

* Wright, *Lick Obs. Bull.*, **7**, 8, 1912.

† Swings, Elvey, and Babcock, *Ap. J.*, **94**, 342, 1941. The lines λλ 3954, 3963 and 3973 were enhanced, together with λλ 4231, 4238 and 4254, on the spectrograms of 1940 December 27 and 31.

‡ Baldet, *Ann. obs. astr. phys.*, Paris, **7**, 58, 1926.

The observed lines of CH^+ arise mainly from the rotational levels $J' = 1$ and 2. This "low temperature distribution" is similar to that observed for *CH*, *NH*, *OH* and *CN*.

The effective slit width for the spectrograms of Comet Cunningham is 1·9 A. near λ 4240; thus the separation of the $Q(1)$ and $Q(2)$ lines of the (0, 0) band is impossible, while $R(0)$ and $R(1)$ may be resolved. The region between λ 3940 and λ 4000 is complex, whereas that around λ 4240 contains no lines other than λλ 4231, 4238 and 4254. The evidence in favour of CH^+ from the (0, 0) band is, therefore, more convincing than that from the (1, 0) transition. No line was observed in the region of the (2, 0) band.

On the whole, the evidence in favour of CH^+ is satisfactory. Like CO^+ and N_2^+, CH^+ molecules are present in the head as well as in the tail, but the extension of CH^+ into the tail is shorter than that of CO^+ and N_2^+.

The CH_2 Band.—Until quite recently a group of strong lines near λ 4050 remained the most puzzling group of unidentified cometary features. Many elaborate discussions have been published on this group, which has been variously attributed to *CH* (Raffety

TABLE VIII

CH^+ Lines in Cometary Spectra

Comets		Laboratory			Comets		Laboratory		
λ	Int.	λ	Notation		λ	Int.	λ	Notation	
4231 *	1	4232·54	$R(0)$	(0, 0)	3954	1	3955·49	$R(1)+R(4)$	(1, 0)
		4229·34	$R(1)$				3954·37	$R(2)+R(3)$	
4238·5	1–2	4237·56	$Q(1)$		3963	1–2	3962·07	$Q(1)$	
		4239·37	$Q(2)$				3964·26	$Q(2)$	
4254·4	1	4254·39	$P(3)$		3972	1–2	3970·82	$P(2)$	

* The two components measured on one spectrogram at λ 4229·1 (int. 1) and λ 4231·8 (int. 1) would be the $R(1)$ and $R(0)$ lines, respectively.

band), C_2 (Deslandres-d'Azambuja system $^1\Pi \rightarrow {}^1\Pi$), *CN* (tail bands), *NaH*, etc. . . . None of these attempts has given a satisfactory identification.

The "λ 4050 group" consists of a strong, fairly sharp line at λ 4051·5, accompanied by weaker lines on either side, as schematized in fig. 2. It is observed in the central parts of the coma, more or less concentrated near the nucleus.

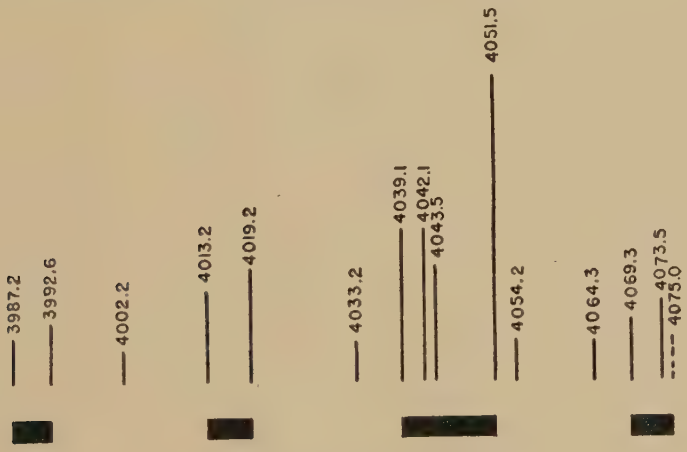


FIG. 2.—*Diagram of the λ 4050 group.*

When observed with a dispersion of 55 A./mm. and an effective slit width of 0·8 A., all the lines are fairly sharp. The lines are not observed in any late-type star, which indicates that they do not belong to a normal molecule consisting of two abundant atoms. None of these lines has ever been observed in interstellar absorption.

In a general way, we may say that the intensity ratio, (int. 4050)/(int. *CH*), increases with the heliocentric distance, the average situation being: int. 4313 (*CH*) > int. 4051 for $r < 0{\cdot}8$, while the opposite is true for $r > 0{\cdot}8$. At large heliocentric distances, the *CH* band is very weak relative to λ 4051. This behaviour is illustrated in Table IX. In Comet Cunningham, whose spectrum was observed from $r = 1{\cdot}2$ to $r = 0{\cdot}5$, the ratio (int. 4050)/(int. *CH*) decreased steadily with r.

There are also individual characteristics of specific comets. In Comet Morehouse ($r \simeq 0{\cdot}94$), the λ 4050 group was extremely weak, while *CN* and C_2 were very intense; but *CH* was also absent.

Certain general conclusions may be obtained regarding the identification of the λ 4050 group.

Let us first consider the case of a diatomic emitter. In order to give sharp lines with a dispersion of 55 A./mm., the diatomic molecule must be a hydride. All the diatomic

TABLE IX

Relative Behaviour of λ 4051 and λ 4313 (CH) in Various Comets

Comet	Heliocentric Distance	λ 4051	λ 4313
Beliavsky	0·33	very weak	strong
1910 I	·47	weak	strong
Brooks	·49	moderate	strong
Cunningham	·52	moderate	strong
Cunningham	·71	strong	strong
Cunningham	·85	strong	fairly strong (< 4051)
Cunningham	·99	strong	moderate
Pons-Winnecke (in 1927)	1·0	strong (> *CN*)	moderate
Delavan	1·20	strong	absent
van Gent	1·25–1·51	strong	very weak
Mellish	1·57	strong	very weak
Whipple	1·5–1·8	strong	hardly visible

hydrides (neutral and singly ionized) of the light elements are known, except NH^+. In any case, however, the emitter cannot be a neutral hydride, otherwise it would have been found in late-type stars. If the emitter is NH^+, which is iso-electronic with CH, the strongest system should be a $^2\Delta \rightarrow {}^2\Pi$ transition. In this case, λ 4051·5 should be a blend of the first lines of the Q branch; λ 4043·5 and λ 4042·1 would correspond to $K = 1$ in the R_1 and R_2 branches and λ 4039·1 would correspond to $R_1 + R_2$, $K = 2$. Lines to the red of λ 4051 would belong to the P branch. As for the lines to the violet of λ 4039, their origin is uncertain. The B_0'' value obtained turns out to be 13 or 14 cm.$^{-1}$, as compared with $B_0''(NH) = 16{\cdot}33$ cm.$^{-1}$.

Several objections to this identification arise. The reduction of B_0'', when passing from NH to the hypothetical NH^+, is rather larger than would be expected from a plot of the B'' values of ionized and neutral molecules (19). The spectrum of NH^+ would also be expected a little more to the red (20). If the λ 4050 group is due to NH^+, the oscillator strength $f(NH^+)$ must be large, and it seems strange that no line of this group has ever been observed as an interstellar absorption line in adequate stellar spectra. Finally it is strange that the intensity of NH^+ lines should increase with heliocentric distance.

Next we must consider the possibility of polyatomic molecules, especially of the simple ones consisting of the cosmically abundant atoms H, C, N and O, and resulting from the photo-dissociation of the chemically stable polyatomic compounds found in meteorites (21). In this direction, Dr. Herzberg has recently suggested (22) that the group may be a ⊥ band of a nearly symmetric top molecule, the observed series of bands (tentatively indicated in fig. 2) corresponding to the sub-bands. The corresponding molecule can only be CH_2 or NH_2^+, of which CH_2 is the more likely. Actually Dr. Mulliken had predicted last year the existence of an electronic transition of CH_2 in the region 4000–4500 A. (23).

From the astronomical point of view, CH_2 is an excellent suggestion, because we should then understand easily why the intensity ratio of λ 4051 to λ 4313 (CH) increases with heliocentric distance, why the band is absent in the late-type stars, and why we do not find it in interstellar space. Since CH results from the photo-dissociation of some saturated parent molecule, we may expect CH_2 to be formed together with CH, or as an intermediary stage.

From these observations, we could conclude in 1942 June that NH^+ is the only diatomic possibility which is left, but that it is not too promising. As for possible polyatomic emitters, CH_2 is very promising, from the astronomical as well as from the physical point of view. During the summer of 1942 Herzberg succeeded in reproducing

the λ 4050 group in the laboratory, an achievement vainly searched for before. Herzberg's announcement (24) is reproduced here:

"On the basis of the assumption that the λ 4050 group is due to CH_2, it was considered likely that it would occur in an electrodeless discharge through methane if the gas was rapidly streaming through. It was found that with moderate pumping speed a continuous discharge through CH_4 gave only the H_2, H and, comparatively weakly, the CH spectrum. However, it was noted that immediately after turning on the discharge the colour was distinctly different from the one established later (bluish white, as compared to the pinkish-white characteristic of hydrogen). This observation suggested that, in spite of the continuous stream of CH_4, the gas was completely decomposed in the discharge except in the first fraction of a second, and the occurrence of CH_2 in the first flash appeared more likely than afterward. The spectrum of an interrupted discharge through streaming CH_4, which was on only for about 1/4 second every 4 seconds, did, indeed, show a new group of bands which proved to be identical with the λ 4050 group observed in comets. With higher pumping speeds, using wider and shorter connecting tubes, it was possible to obtain the λ 4050 group even without interrupting the discharge, although it was then more strongly overlapped by the H_2 spectrum.

"In the upper part of Plate 5 the spectrum of an interrupted discharge through streaming CH_4 (with iron-arc comparison spectrum) is reproduced. It has been enlarged to the same scale as a spectrum of Comet 1940 *c*, which is given in the lower part of the plate, also with *Fe* comparison spectrum. From a comparison of the two spectra, the identity of the λ 4050 group occurring in comets with the group observed in the laboratory seems to be definitely established, particularly if it is remembered that (1) there are a few H_2 and CH lines overlapping the laboratory spectrum, (2) small differences may be expected on account of the different mechanism of excitation, and (3) this group is the only new feature of the laboratory spectrum, which otherwise consists only of H, H_2 and CH lines and bands in the whole visible and ultraviolet regions.

"The freedom from impurities shown by the spectrum makes it practically certain that the λ 4050 group is due to a molecule containing carbon and hydrogen. The method of excitation suggests a molecule intermediate between CH_4 and CH. Thus the previous conclusion (22) that the emitter is CH_2, which was based on the structure of the spectrum, is strongly supported, although, from the conditions of excitation alone, CH_3 and CH_4 cannot be excluded. By an investigation, now under way, of the fine structure of these bands, a definite decision will be possible."

Thus was identified the first polyatomic molecule of comets. Herzberg is now engaged in the analysis of his laboratory spectrograms of the "λ 4050 group" (25).

3. *Cometary Emissions in the Visual Region*

Spectra of comets have been observed toward the long wave-lengths up to λ 6650 approximately; some observations have been made beyond λ 6650, but they are only of a preliminary character and do not provide reliable identifications. The yellow and near red regions are comparatively poorly known, the reason being that modern grating spectrographs have hardly been used to investigate comets. Yet, despite the low dispersion always used in the visual region, it seems desirable at the present time to collect the data available in the region $\lambda > 4800$ A. The wave-lengths of the emission lines to the red of λ 4800 are given in Table X, from which have been excluded the well-identified C_2 and CN bands (26). Some of the faint lines listed in the table may be spurious, especially those which are concentrated near the cometary nucleus where the intensity of the reflected solar spectrum is strong.

The strongest unidentified line is λ 6299 which behaves very much like the CH_2 band. At large heliocentric distance, λ 6299 stands out conspicuously; for example, in Comet 1942 *f* ($r = 1{\cdot}36$), there is hardly any trace of CH, the NH and C_2 bands are

Table X

Cometary Emissions in the Spectral Region $\lambda > 4800$

Brooks [1]	Peltier [2]	Finsler [3]	Cunningham [4] $r=0.85$	Cunningham 0.71	Cunningham 0.69	Cunningham 0.65	Cunningham 0.58	Cunningham 0.52	Cunningham 0.49	Cunningham [5] $r=0.5$	Whipple 2 [6]	Whipple 2 [5]	Nuclear Features [7]	Adopted Wavelength	Suggested Identification
4837·8 (0)				38·3 (2)	39·7 (1*n*)	38·8 (1+)	39·6 (2*n*)	40·0 (1+)			36·5 (0*n*)		40·4 (3)	4838·9	
			67·6 (1*s*) [8]	69·3 (1?)				69·2 (1−)					66·6	4868·2	
			77·0 (0+?)	76·0 (1?)	75·2 (0+)		} 78·8 (1*n*)				} 80 (00*n*)		74	4876·0	
				84·9 (1?)		84·9 (1)							79·5	4883	
4925·5 (0+)	25·6 (..)		23·8 (2)	25·2 (2)	26·2 (1+) [9]	25·8 (2)	25·6 (2)	25·4 (2)					28·5 (3)	4925·7	
			36·0 (1−)		38·0 (1)									4937·0	
			54·9 (0+)	52·9 (0+)	54·0 (1−)	53·3 (1)		51·6 (1)			} 46 (00*n*)		} 48	4953·3	
			62·9 (0+)										62·5	4962·7	
			70·4 (0+)	71·7 (0+)									71·1	4971·1	
			06·0 (1−)										08	5007·0	
5178 (0)			85·5 (2)								87·6 (2*n*) [10]		78 (0)	5186·5	
				43·3 (1−) [10]		43·2 (1+) [10]	42·7 (1+) [10]				46 (1*n*)			5243·1	NH_2
				59·0 (1−) [10]										5259·0	
				83·5 (1−) [10]										5283·5	
			16·4 (1)	18·8 (1+)	19·5 (1+) [10]	18·5 (2+)	19·4 (2)							5318·5	N_2?
			26·0 (1−)	} 32·9 (1)	33·6 (1+) [10]									5326·0	N_2?
			36·8 (1−)			36·2 (2)								5336·5	N_2?
			57·0 (1*n*)	52·7 (1)	57·9 (1+)	52·8 (2)					56 (00)			5355·3	
			92·0 (1)	83·2 (1+)	84·0 (2?) [10]									5386·4	NH_2
5418·5 (0)											18 (00*n*)		18·5 (0)	5418·3	NH_2
5428·3 (1−)		29 (2*n*)	26·5 (4)	28·0 (4)	29·8 (3) [8]	28·3 (4)	28·8 (3)				25·7 (1*n*)			5428·0	NH_2 [20]
		43 (2*n*)	43·7 (4)	43·2 (4)	44·0 (3) [8]	47·3 (4)	47·0 (2)		44·7 (1)					5445·0	NH_2 [20]
5692·5 (0)	} 97 (..)		79·1 (1)		89·8 (0+)						} 95 (2*n*)	95 (1*d*)	925 (0)	5689·0	NH_2
5705 (1*n*)		10 (1*n*)	01·0 (2+)	99·0 (2+)	04·5 (1*n*+) [11]	99·9 (3*n*)	01·3 (3)	95·6 (2*n*)	02·1 (2) [10]			05 (1*d*)	05 (1*n*)	5702·7	NH_2
					18·9 (1)	19·4 (1+)								5719·2	
5732 (0)			35·2 (2)	} 31·0 (2)	31·6 (2)	31·3 (2)		28·9 (1*n*+)			32 (1*n*)	32 (1*s*)	32 (0)	5731·5	NH_2
		37 (1*s*)		} 39·5 (1+)	38·9 (1+)	41·3 (1+)	38·7 (1*n*+)					42 (1−)		5740·4	
		47 (1*s*)		53·4 (1)	51·4 (1)	54·7 (1)						56 (0+)		5754·1	
5779 (1−)												{ 68 (0+)	79 (1−)	5768	} NH_2
												89 (0)		5789	
	14 (..)			01·3 (1−)	05·8 (0+)						08 (00*n*)			5805·0	NH_2
				92 (1?)	93 (1*n*?)	92·9 (2*n*)	93·2 (1*n*)	*Na*	*Na*					5892·8 [12]	
5977 (1−)	71 (..)	81)(2*n*)	78·0 (4)	78·1 (4)	75·0 (4)	78·8 (5)	76·3 (4)	76·1 (4)		75 (0+)	78·7 (2*n*)	75 (3*d*)	77 (1−)	5976·8	NH_2
5994 (1−		98 (1*n*)	97·4 (3)	96·5 (3)	92·8 (2)	96·2 (1+)	94·1 (2)	95·0 (2)	89·0 (3*n*) [10]	95 (0+)	97·2 (1*n*)	95 (2)	94 (−1)	5996·0	NH_2

6020·5 (0)		15 (1*n*)	20·2 (2)	18·1 (2)	21·7 (2)	21·8 (1+)	(13)	17·6 (2)[8]		21 (0+)	20 (00*n*)	18 (1−)	20·5 (0)	6019·4	NH_2
	45 (..)		34·9 (1*n*+)	41·0 (2−)	(14)	(15)	(13)	34·8 (1)						6036·9	NH_2
			54·4 (1)	57·0 (1?)	(14)	(15)	(13)	55·3 (1)	51 (1*n*)		50 (0*n*)			6053·5	C_2+NH_2
	79 (..)		79·8 (1+)					90·8 (2)						6085·3	NH_2
	02 (..)	00 (1*n*)	96·7 (2+)	99·0 (3)	96·2 (2+)	(16)	(17)	02·4 (2)	98 (1)	99 (0)	97 (1*nn*)	96 (1+)		6098·0	
					09·6 (2)	(16)	(17)					10 (0+)		6110·2	
		18 (0*n*)	13·7 (4)	19·5 (2)	20·6 (1?)	(16)	(17)	17·8 (2)	17 (4)					6120·9	C_2
							50·1 (0+)				47 (0*nn*)			6148·6	
				64·4 (1−)	73·4 (0+)		74·1 (1)							6170·6	NH_2
											00·2 (0*n*)			6200·2	(18)
	72 (..)										44·1 (0*s*)			6244·1	NH_2
6300 (1)	92 (..)	06 (3)	98·0 (5)	97·2 (5)	99·3 (5)	98·7 (6)	96·0 (2)	96·8 (5)	[OI]	00 (2)	86 (00*s*)			6279	NH_2
											97 (3*n*)	00 (5)[10]	00 (5)	6298·7	NH_2
		38 (2)	30·4 (1+)			29·3 (1)			37·6 (1)	36 (0)	36 (1)	20 (0+)		6320	
											45·6 (1−)	33 (2)		6333·4	NH_2+CN
		67 (1)	62·3 (1)						[OI]		61 (0*nn*)	46 (0+)		6345·8	
	30 (..)										86·2 (0*n*)	62 (1)		6363·4	NH_2
									13·7(1)					6386·2	
											46 (00*s*)	00 (0+)		6407	NH_2
6578 (0)		83 (1)												6546	NH_2?
6598 (1)										81 (0)		79 (0+)	78 (0)	6580	NH_2
6619 (1)		24 (2)											98 (1)	6598	NH_2
		46 (1)								19 (1+)	25 (00*s*)	20 (3)	10 (1)	6621	NH_2
											38·4 (0*n*)			6642	NH_2
										68 (0−)		75 (0+)		6668	NH_2?
										85 (0)				6685	

(1) W. H. Wright, *Lick. Obs. Bull.*, **7**, 8, 1912.
(2) Baade and Minkowski, *Pub. A.S.P.*, **48**, 277, 1936.
(3) R. L. Minkowski, *Pub. A.S.P.*, **49**, 276, 1937.
(4) Unpublished measurements by the author.
(5) A. McKellar, private communication.
(6) R. L. Minkowski, private communication.
(7) F. Baldet, *Ann. Obs. Astr. Phys.*, Paris, **7**, 1926.
(8) Long line.
(9) Probably double at λ 4924·3–λ 4928·5.
(10) Nuclear.
(11) Possibly double at λ 5700·7–λ 5705·8.
(12) This nebulous feature is not the *D*-line of *Na* which became definitely present as a sharp line for $r=0{\cdot}52$.
(13) Broad band with structure, from λ 6017 to λ 6058.
(14) From λ 6021 a band extends to λ 6062 with a maximum at λ 6050.
(15) Broad band, intensity 1+, from λ 6032 to λ 6059.
(16) Band from λ 6095 to λ 6124 with probable maxima at $\lambda\lambda$ 6100·4 (2^+), 6111·0 (2) and 6121·6 (2^+).
(17) Band from λ 6091 to λ 6122.
(18) Not due to C_2 (0, 2) only.
(19) Extending from λ 6296 to λ 6303. Measured by Swings and Struve in Comet Whipple 2: $\lambda\lambda$ 6299·0 (5), 6330·5 (1), 6345·6 (1−), 6366·3 (1), 6380·4 (0?).
(20) Identification not satisfactory, since the cometary line is long.

weak, but λ 6299 and λ 4051 CH_2 are both quite strong. There is no strong absorption band in late-type stars at λ 6299. A number of features to the blue and to the red of λ 6299 behave similarly with heliocentric distance, but additional observations are desirable on this point. Provisionally we suggest calling this group of emissions the "λ 6300 group," and there is every reason to believe that it belongs to a polyatomic molecule.

The only identification which suggests itself for the "λ 6300 group" is the alpha band of ammonia. The α-band appears easily in many types of flames (27) and discharges (28). Its structure is very complex; of more than 3000 lines observed with high dispersion, some 300 have been measured by Rimmer. Excellent reproductions of the low-dispersion spectrograms of the hydrogen-nitrous oxide and methane-nitrous oxide flames, in which the α-band is present, have been published by Gaydon (27). In the hydrogen-nitrous oxide flame, two intensity maxima at λ 6300 and λ 6330 are very outstanding, but they vary somewhat in intensity from plate to plate. In the methane-nitrous oxide flame, the features at λ 6300 and λ 6330 are not outstanding. In Eder and Valenta's reproduction of the ammonia-oxygen flame, the features at λ 6300 and λ 6330 are also conspicuous. From Gaydon's observations it would appear that λ 6300 and λ 6330 are "not of the same origin as the rest of the α-band, or that for some reason they are particularly sensitive to changes in the temperature of the flame." In 1927 Hulthén and Nakamura (29) had already suggested that the α-group "is emitted by the excited NH_3 or NH_2 molecules, or a mixture of both, as one can distinguish with some degree of certainty two different systems in α." Whatever doubt there remains as to the molecules which actually give rise to the α-band, it is certain that they must be nitrogen-hydrogen polyatomic combinations (probably not ionized), NH_2 playing the dominant rôle.

The electronic structure of NH_2 has been considered by R. S. Mulliken (30), who has kindly provided a number of additional data. The level diagram (fig. 3) indicates

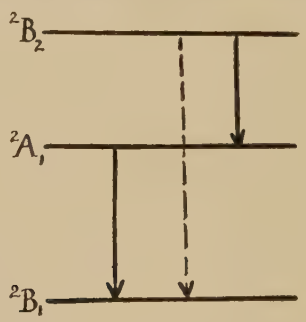


Fig. 3.—*Level diagram of the NH_2 molecule (after R. S. Mulliken).*

the nature of the expected transitions on the assumption that the apex angle is fairly wide, as may be inferred by analogy with Herzberg's interpretation of the cometary CH_2 group (31). The diagram suggests that there might be NH_2 spectra observable in the visible region. It seems hardly likely that the interval between $^2B_1$ and $^2B_2$ could be more than four volts. The position of $^2A_1$ would depend a good deal upon the apex angle; for a smaller apex angle, such as that for H_2O, the levels $^2A_1$ and $^2B_2$ might be close together or even reversed in position.

From all of this it appears that there may be either one or two moderately intense spectra of NH_2 in the visible region. It is also possible that the molecule has an almost metastable level if the highest level shown in fig. 3 is actually the middle one; however, this is improbable (32).

In the absence of an analysis of the α-band, it is impossible to predict in detail the

structure of the emission by cometary NH_2 molecules excited by solar radiation. Hence there remains only the crude method of comparing the wave-lengths of the intensity maxima in the laboratory source and in the comet, it being well understood that slight differences in wave-length and larger ones in intensity may be expected. Moreover, it should be pointed out that the *NH* bands are strong in comets, and that the *NH* molecules must result from the photo-dissociation of chemically stable parent molecules (probably ammonia) liberated by the solid constituents of the comet. Hence the presence of NH_2 bands is likely, since it is known (33) that the photo-chemical decomposition of ammonia takes place almost exclusively according to the reaction

$$NH_3 + h\nu \rightarrow NH_2 + H.$$

It seems very probable that the cometary features at λ 6299 and λ 6333 are identical with the strong lines of the α-band. From wave-length and intensity comparisons it is also hard to escape the conclusion that an important part of the emissions, from the nuclear region, of the λ 6300 group—besides λ 6299 and λ 6333—actually belongs to the α-band of ammonia (see Table X). The author has just learned that A. McKellar and R. Minkowski also identified the NH_2 bands independently; see Swings, McKellar and Minkowski, *Ap. J.*, in press.

As to the other unidentified features the following remarks may be made:—

(*a*) The cometary line λ 4839 is very near to the strong Vegard-Kaplan band of N_2 at λ 4837·1. But the identification is very doubtful, since other Vegard-Kaplan bands of similar intensity in the night sky are absent.

(*b*) The features at $\lambda\lambda$ 4868, 4937 and 4971 are close to the wave-lengths of unidentified absorption bands found by Sanford (34) and Shane (35) in carbon stars. In carbon stars λ 4976 has been tentatively attributed (36) to the convergence of the $\Delta v = 0$ sequence of C_2.

(*c*) The three cometary emissions at $\lambda\lambda$ 5318, 5326, 5336 may be identical with a new system of nitrogen recently found by Gaydon (37).

(*d*) The (4, 1) band of the red system of *CN* may contribute to the cometary feature at λ 6333.

(*e*) The cometary emission at λ 5996 is not due to NO^+. A strong band with origin at λ 5999 has been attributed to NO^+ (38), but by comparison with *CO* it is certain that this band cannot be a resonance transition of NO^+. By analogy with *CO*, we should expect the absorption required to reach the higher electronic level of the λ 5999 band of NO^+ to be situated in the far ultraviolet; hence excitation by solar radiation would be very inefficient.

(*f*) The cometary emissions at λ 6299 and λ 6364 are occasionally blended with the [*OI*] lines of the night sky.

4. *The Excitation Mechanism and the Rotational Structure of the Cometary Bands*

It has usually been assumed that the molecular bands, and also the *Na* lines, are emitted in a fluorescence process excited by solar radiation (39). This suggestion was put forward by Schwarzschild and Kron in 1911 (40), and developed theoretically by Zanstra (41) in 1928, and by Wurm (42) in 1934. The main result of Zanstra and Wurm is that the observed luminosities of comets having strong emission spectra are of the order of those calculated on the basis of a fluorescence excitation. Wurm also concluded, from the estimated intensity of the C_2 bands, that the pressure in the nucleus is probably less than 10^{-10} mm., and much less than this in the head and tail. This indicates that collisional effects must be unimportant in cometary atmospheres.

A more direct test of the fluorescence hypothesis is provided by Öhman's measurements of polarization (43) in Comet Jurlof, and especially in the spectra of Comet Cunningham and Comet Paraskevopoulos. The theoretical basis is the following (44):

For transitions such as $\Sigma \rightarrow \Sigma$, $\Pi \rightarrow \Pi$, the total polarization of fluorescence bands excited by unpolarized light should be equal to 7·6 per cent.; for transitions such as $\Sigma \rightarrow \Pi$, . . . (involving a change in Λ) the polarization should be 19 per cent. "If the values obtained for comets should be found to be lower than the values given above, it would show the presence of an additional unpolarized excitation of molecules, such as excitation by electron impacts, collisions, etc., the amount of which could be easily estimated from the degree of polarization found" (Mrozowski, *loc. cit.*).

Such measurements of the polarization of cometary bands are difficult to perform, yet those made by Öhman have met with a great deal of success. For the C_2 and CN bands of Comet Cunningham, Öhman finds a polarization of about 10 per cent., which is approximately that to be expected for a pure fluorescence excitation. In Comet Paraskevopoulos Öhman finds a much higher polarization, about 24 per cent.; this Öhman attributes to the fact that most of the light of this latter comet (which had a strong solar spectrum and only faint bands) is due to diffuse reflection, diffraction or scattering of solar light by cometary particles.

Öhman's success is promising, and renewed attempts should be made with a view to increasing considerably the accuracy of the measurements. However, since such very accurate determinations are very delicate, it is desirable to search for a more direct, spectroscopic test of the fluorescence hypothesis.

Such a test was provided by the author (45) in 1941 and was the object of important microphotometric work by McKellar (46) in 1942 and 1943. The question is to decide whether the molecules are brought into the excited state by absorption of radiation only, or whether dissociation or collisional processes could provide the excitation energy. For example, does the CN emission result from a photo-dissociation such as $C_2N_2 + h\nu \rightarrow CN_{\text{exc}} + CN$, or simply from a pure resonance excitation $CN + h\nu \rightarrow CN_{\text{exc}}$?

There is a possibility of deciding between these two mechanisms on the basis of the intensity distribution among the rotational lines of the individual bands. It was shown in sections 1 and 2 that except for the Swan bands of C_2 which have an appearance similar to that obtained in the laboratory, all the other bands show a peculiar distribution of intensity among the rotational and vibrational transitions, this being especially characteristic in the case of CN. In all the cometary molecules which have a permanent electric dipole—and therefore excluding $C^{12}\,C^{12}$—only the lines arising from the low rotational levels are observed:

$K' \leqslant 3$ for OH; $\leqslant 2$ for NH; $\leqslant 6$ for CH; $\leqslant 2$ for CH^+; $\leqslant 25$ for CN.

But the intensity distributions among these lines of low rotational quantum number deviate considerably from the smooth distributions in equilibrium at a low temperature. For example, in the excited level $v' = 0$ of CN, the rotational states $K' = 2$ and 3 (always), 8, 11 and 15 (often) are favoured as compared with $K' = 5$, which is underpopulated (47). The rotational intensity distribution is not quite the same in all comets, but all manifest a number of favoured excited rotational levels.

If we assume an excitation in comets resulting purely from one or several photo-dissociations or from electron impacts, we must admit that the selective favouring of certain rotational levels is due to these mechanisms. No laboratory or theoretical data favour such an effect, and it would be impossible to explain in this way the variations of the observed CN structures with heliocentric distance or from comet to comet.

Let us now assume that the excitation of the CN cometary molecules is due exclusively to the absorption of solar radiation. The population in an excited rotational level K', from which the two emission lines $P(K'+1)$ and $R(K'-1)$ arise, can then be expressed as follows:—

$$N'_{K'} \propto N''_{K'+1} \cdot p_P^{\text{abs}} \cdot I_P + N''_{K'-1} \cdot p_R^{\text{abs}} \cdot I_R \qquad (3)$$

where:

$N''_{K'-1}$ and $N''_{K'+1}$ are the populations in the rotational levels $K''=K'-1$ and $K''=K'+1$ of the ground electronic and vibrational state;

p_P^{abs} and p_R^{abs}, the transition probabilities of the absorption line s$P(K'+1)$ and $R(K'-1)$ and

I_P and I_R are the intensities of solar radiation for the wave-lengths of $P(K'+1)$ and $R(K'-1)$, corrected for the radial velocity of the Sun with respect to the comet (ordinarily this correction is of the order of $\pm 0{\cdot}25$ A.).

Whatever the distribution $N''_{K''}$ may be (the simplest case is a continuous function of K'' with only one maximum), $N'_{K'}$ will depend on the spectral distribution of the solar radiation. The important effect of the Fraunhofer lines appears strikingly when one plots the wave-lengths of the P and R lines on a map or a photometric tracing of the solar spectrum. The deep minima in the solar spectrum in the region of $P(6)$ and

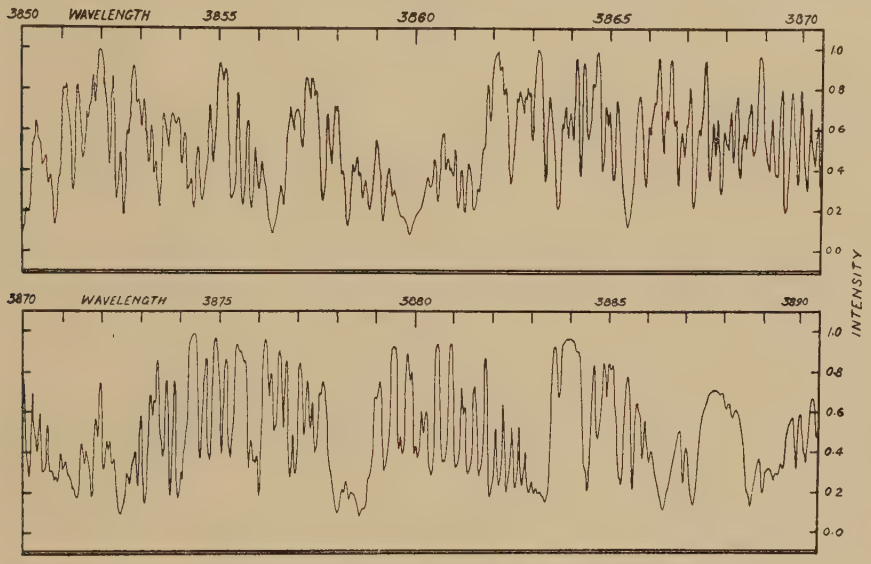


FIG. 3A.—*Contour of the solar spectrum near the λ 3883 band.*

$P(7)$, and between $R(2)$ and $R(7)$ are undoubtedly the cause of the very low intensity of the P and R lines corresponding to $3 < K' < 8$. Whatever the radial velocity may be, $P(6)$ and $P(7)$ will always fall in a deep minimum of the solar spectrum, caused mainly by λ 3878·02 (*Fe*I, lab. int. 400, ⊙ 8) and λ 3878·57 (*Fe*I, lab. int. 300, ⊙ 7) (fig. 3A). Also $P(5)$ usually falls in a solar spectral region fainter than that near $P(4)$. Another minimum in solar intensity occurs between $P(9)$ and $P(12)$. On the whole, it is possible to explain the observed structures in cometary spectra by assuming that the intensity maxima and minima result from solar excitation influenced by the Fraunhofer lines.

The effect of the radial velocity of the comet with respect to the Sun should be pointed out. Whereas no probable radial velocity could prevent $P(6)$ and $P(7)$ from falling in a weak region, certain relative intensities may be very sensitive to a change in radial velocity which could bring the cometary absorption line inside or outside a strong Fraunhofer line. These considerations, when applied to various comets having different radial velocities with respect to the Sun, but with similar heliocentric distances, have given a satisfactory interpretation of the observed *CN* structures. These same considerations may, of course, be equally well applied to one comet at different heliocentric

distances. Similar considerations when applied to the other molecules, *CH*, *NH* and *OH* give a satisfactory qualitative explanation of band structures.

Quantitative Test of the Fluorescence Theory in the case of the CN Bands.—All the preceding considerations are of a qualitative character, and although they provide very strong evidence in favour of a pure fluorescence excitation, a quantitative microphotometric discussion was highly desirable. Such an investigation was also likely to provide interesting data on the rotational distribution of the molecules in the ground electronic state. This has been performed by McKellar for Comets 1939 *d* (Jurlof) and 1940 *c* (Cunningham), using slit spectrograms taken at the Dominion Astrophysical Observatory in Victoria, B.C. Profiles were obtained for the λ 3883 (0, 0) band of *CN*, the λ 4315 band of *CH*, and the $\Delta v = +1$ sequence of C_2. Fig. 1 gives the *CN* band profile of Comet 1940 *c* for $r = 0{\cdot}54$ (mean of three spectrograms at $r = 0{\cdot}56$, 0·54 and 0·52) and for $r = 0{\cdot}92$ (mean of three exposures at $r = 0{\cdot}97$, 0·93 and 0·87). There is a decided difference in the profile of the *P* branch for the two heliocentric distances, which is most directly and readily interpreted as an increase in "rotational temperature" of the *CN* molecules as *r* decreases. This effect had been found previously (48), but is now more clearly defined. As mentioned by McKellar, it explains the striking and long unexplained difference between the *CN* bands in the spectra of Comet Zlatinsky (1914 *b*) at $r = 0{\cdot}67$ and Comet Mellish (1915 *a*) at $r = 1{\cdot}52$ (49).

To calculate the profiles of the *CN* bands on the assumption of a pure fluorescence mechanism, McKellar adopts a Boltzmann type of distribution for the rotational levels of the ground state. The "rotational temperatures" were chosen to give the best agreement in wave-length between the observed main maximum of the *P* branch and the corresponding maximum of the computed intensity curve. In applying formula (3) the intensities were taken from the Utrecht Photometric Atlas of the Solar Spectrum (50), with due correction for radial velocity shift (fig. 3A). The computed relative intensities of the emission lines were then plotted as rectangles of height proportional to the calculated intensity and width equal to the projected spectrographic slit width (51). A few obvious transformations of the calculated diagrams were applied, in order to make them as nearly comparable as possible with actual profiles. The calculated *R* branch remains still too intense, compared with the *P* branch, but this does not affect the main conclusions.

The results of the calculations are shown in figs. 4 and 5 for Comet 1940 *c*. It is apparent at once that virtually every intensity maximum has its corresponding counterpart in the calculated profile. Had the effect of the contour of the solar spectrum been neglected, then the calculated profiles would have been smooth, with no subordinate maxima.

These results provide the most direct observational proof of the fluorescence mechanism of cometary emission.

The influence of the radial velocity, already considered by the author in 1941, has been studied more in detail by McKellar, who showed that the considerable shift of the *CN* maximum in Comet 1939 *d* ($r = 0{\cdot}59$) relative to Comet 1940 *c* ($r = 0{\cdot}54$) is due to the difference in radial velocities. The radial velocity of Comet 1940 *c* with respect to the Sun was about 33 km./sec. of approach, while for Comet 1939 *d* it was 16 km./sec. of recession. In Comet 1940 *c* the whole solar spectrum was effectively shifted some 0·45 A. to the violet; therefore the strong region of the solar spectrum from λ 3883·4 to λ 3883·9 (see fig. 3A) was effectively at λ 3883·0 to λ 3883·5 and so helped greatly to increase the populations of the levels from $K' = 21$ upwards. However, for Comet 1939 *d*, the solar spectrum was effectively shifted some 0·21 A. to the red, which caused an underpopulation of the levels from $K' = 20$ upwards.

It is also certain that slight changes in radial velocity may affect appreciably the intensity of the cometary *CN* emission because of the shift of the solar spectrum: this point deserves further study.

Other Molecules.—The author's qualitative discussion of the *CH*, *NH*, *OH* and CH^+ bands, and McKellar's quantitative study of the λ 4315 *CH* band show that the fluorescence mechanism is also responsible for the excitation of these other molecules,

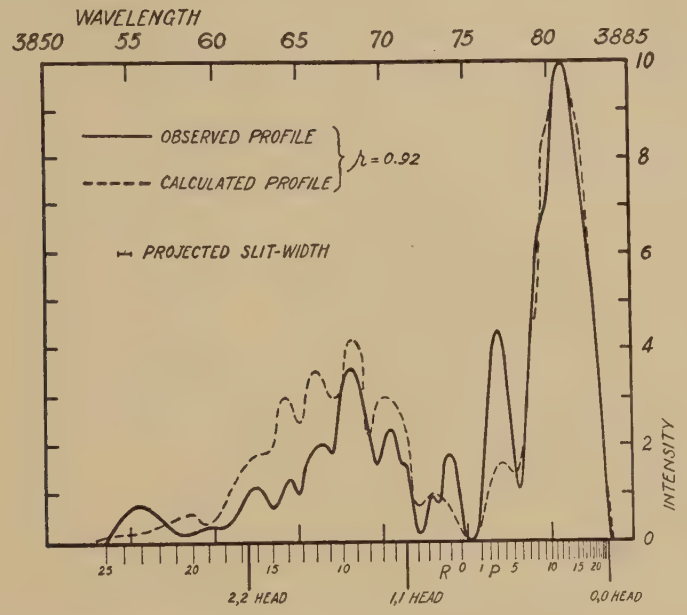


FIG. 4.—*Observed and calculated profiles, CN bands, Comet* 1940 *c*, $r = 0{\cdot}92$.

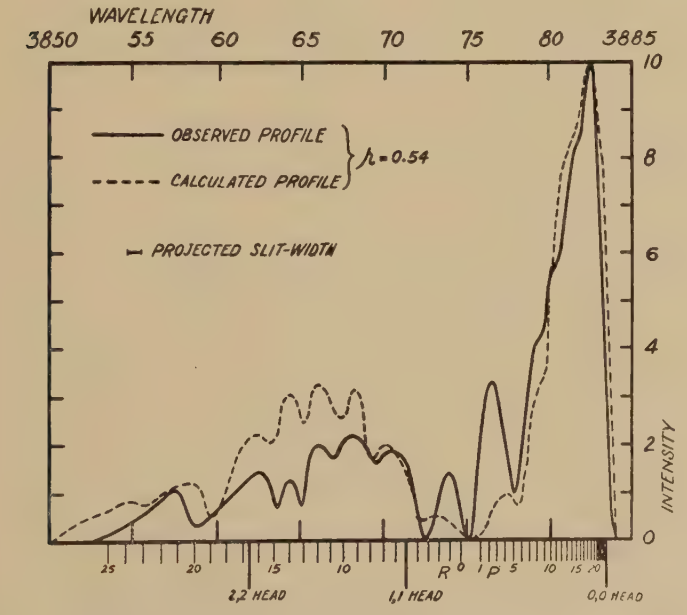


FIG. 5.—*Observed and calculated profiles, CN bands, Comet* 1940 *c*, $r = 0{\cdot}54$.

but the characteristics of their spectra render the agreement between observation and theory less spectacular than for *CN*.

In the case of the identification of CH^+, an examination of the intensity distribution in the exciting solar spectrum shows that the absorption transitions to the level $K' = 3$,

$v' = 0$ are more reduced by Fraunhofer lines than those corresponding to $K' = 2$, $v' = 0$. Hence the intensities of the bright lines $R(2)$, $Q(3)$ and $P(4)$ are reduced relative to those of $R(1)$, $Q(2)$ and $P(3)$ in the (0, 0) band.

The identification of OH^+ is especially complex, not only on account of the proximity of the *CN* features, but also on account of the extremely complex profile of the solar spectrum in the region $\lambda\lambda$ 3565–3590. The intensity distribution among the OH^+ lines must certainly be very complex.

When the analysis of the laboratory spectra of CH_2 and NH_2 are completed, the discussion of the intensity distributions in the corresponding bands in the cometary spectra will be interesting. For example, in the solar spectrum a large number of strong absorption lines due to *Mn*, *Fe* and *Mg* appear in the region of the CH_2 group; especially the intense *Fe* lines $\lambda\lambda$ 4055·8 (solar intensity 30), 4063·6 (int. 20) and 4071·7 (int. 15). These should perturb the intensity distribution in the cometary CH_2 band.

All these considerations show that the work of identification of the features of cometary spectra must proceed with great caution. The final test of an identification should be based on the decomposition of the exciting radiation into a number of monochromatic excitations. The excited pattern is the superposition of resonance doublets (or singlets or triplets according to the type of electronic transition), each consisting of a *P* and an *R* line, and each having a specific intensity. We should thus not expect the pattern to resemble too closely the intensity distribution in a laboratory spectrum, even of a low temperature source (52).

Distributions of Cometary Molecules in their Rotational and Vibrational Levels.—In the absence of collisional effects, the primary mechanism which is involved in populating

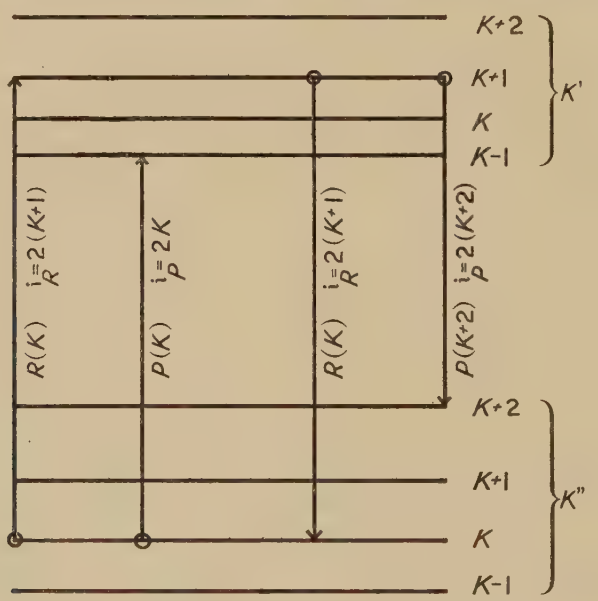


FIG. 6.—*Transition probabilities in a $\Sigma \rightarrow \Sigma$ band.*

the vibrational and rotational levels is the absorption of solar radiation. This point was emphasized by Wurm a few years ago (53), and is illustrated by the case of the rotational levels of a diatomic molecule, the corresponding band having no *Q* branch (fig. 6). In absorption, the $R(K)$ line is stronger than $P(K)$ (see the i-values in fig. 6): this tends to populate the higher K' levels in the excited electronic state. In the emission from level $K+1$, the $P(K+2)$ line is stronger than $R(K)$: this tends to populate the higher K'' levels.

If the solar radiation did not have absorption lines, we should expect a smooth distribution among the rotational levels. Whether this distribution would be of the low- or the high-temperature type depends on the depopulating processes. Downward transitions between rotational levels belong to the pure rotational far infra-red spectrum. If this spectrum is permitted—which is the case for heteronuclear diatomic molecules—the downward transitions will be able to depopulate the K'' levels. Since the intensity ratios $K+1/K$ and $K+2/K+1$ decrease with K, the populating processes for high values of K become compensated by depopulating processes, the deciding factor being evidently the relative values of the time between successive absorption processes and the lifetime of the rotational states. This explains why the bands of *CH*, *OH*, *NH*, *CN* and CH^+ have, on the whole, low-temperature rotational distributions. Of course, beside the heliocentric distance, the individual characteristics of the molecules are of utmost importance in determining the actual distributions (53). These characteristics are mainly the dipole moments (and thus the mean lifetimes of the rotational states) and the band structure (*e.g.* the presence of a strong Q branch, as in *CH*, reduces the tendency of molecules to reach higher K values).

The situation is quite different for a homonuclear molecule such as $C^{12}\,C^{12}$, for which the pure rotational spectrum is forbidden. Molecules may then accumulate on higher rotational levels and give bands of high-temperature rotational distributions. Considerations of a similar character apply to the vibrational levels.

On the basis of these general considerations we may understand why the profiles of the bands of the isotopic $C^{12}\,C^{13}$ molecule at $\lambda\lambda$ 4745, 4723 and 4706 are different from those of the corresponding bands of $C^{12}\,C^{12}$. Actually the bands of $C^{12}\,C^{13}$ are hazy, whereas the $C^{12}\,C^{12}$ bands have sharp edges. The difference of rotational intensity distribution in $C^{12}\,C^{12}$ and $C^{12}\,C^{13}$ is due to the fact that whereas the highly excited rotational levels of the ground electronic state of $C^{12}\,C^{12}$ can be depopulated only by quadrupole emission in the far infra-red pure rotation spectrum, a dipole mechanism of greater probability (although still intrinsically small) operates for $C^{12}\,C^{13}$. In other words, the $C^{12}\,C^{12}$ bands would be reduced to the first lines of the branches at very large heliocentric distances only, whereas the depopulating process operates at much smaller heliocentric distances for $C^{12}\,C^{13}$.

Next we must consider the influence of the solar absorption lines on the populations of the rotational states. For example, if we start from molecules on the level $K''=K$ (fig. 6), and if $\lambda_{R(K)}$ coincides with a strong solar line, the population of level $K''=K+2$ will be reduced. It is easily seen that, as a result, a more or less irregular distribution amongst the rotational states K'' may be brought about. On the whole this tends to increase the contrast between subordinate maxima and minima in the rotational bands. It would explain why, in figs. 4 and 5, the contrast between the calculated maxima (at $K' \simeq 2$) and minima (at $K' \simeq 5$) in the P branch of the *CN* band is smaller than the observed contrast.

McKellar (54) has just completed a discussion of the rotational distribution of the *CH* molecules in the nucleus of Comet 1940 *c*. His result is that nearly all the molecules exist in the two lowest rotational levels, $K''=1$ and 2.

A rigorous theoretical treatment of this problem along the theory of cyclical transitions would be very desirable, especially for the *CH* molecules for which quantitative results have been obtained by McKellar.

These considerations illustrate the artificial character of the concepts of vibrational and rotational "temperatures" of cometary bands. As may be expected the "temperatures" obtained from different molecules may differ considerably. McKellar reported that the *CN* bands in Comet Cunningham correspond roughly to $T=435°\ K$ for $r=0{\cdot}54$, whereas for *CH* the temperature is only 200° *K*.

The general increase in "rotational temperature" with decreasing heliocentric distance is a well-established fact for the (0, 0) band of *CN* (55). Great care, however,

has to be exercised when discussing variations in rotational intensity distribution with heliocentric distance, since the change in radial velocity also affects the distribution.

Variations in rotational intensity distribution similar to those found for *CN* have also been observed for *OH*, *NH* and *CH*. For example, Table I shows the striking differences of rotational distribution in the *OH* band in different comets. In Comet 1941 *d* (r from 1·51 to 1·25, $dr/dt \simeq -22$ km./sec.) and in Comet 1942 *a* ($r \simeq 1{\cdot}75$, $dr/dt \simeq -13$ km./sec.), the intensity distribution among the *OH* lines is very different from that in Comet 1940 *c* ($r \simeq 1$, $dr/dt \simeq -35$ km./sec.). In Comets 1942 *a* and 1941 *d* the lowest rotational levels of *OH* are favoured, as compared with Comet 1940 *c* (56). It can easily be seen that this is not due to the different radial velocity shifts of the exciting solar radiation, but rather to the different types of rotational distribution corresponding to the heliocentric distances.

Similar results have been obtained for *CH* (57) and *NH* (58), and it will be interesting later on to discuss the cases of CH_2 and NH_2, once these spectra have been classified.

The vibrational distributions depend also on the heliocentric distance; this was proved to be true for heteronuclear molecules of low vibrational temperature, such as *CN* (59), as well as for the homonuclear molecule of high vibrational temperature, $C^{12}\,C^{12}$ (60).

5. *General Considerations on Cometary Physics*

From the considerations of sections 1, 2 and 3, it appears that the following molecules have been identified in comets: *OH*, *NH*, *CN*, *CH*, C_2, CH^+, CH_2, CO^+, N_2^+ and probably NH_2 and OH^+. It is well known also that the *D* lines of *Na* appear at small heliocentric distances.

Beside the molecular bands and the *Na* lines, all the spectra of comets show a solar absorption spectrum (see Plate 4) which results from the reflection or scattering of solar light by the solid particles present, not only in the nucleus, but also in the head and even in the tail.

One may wonder how a "low-temperature source," like a cometary atmosphere, can contain radicals such as *OH*, *CH*, *CN*, *NH*, C_2, that are not chemically stable. Actually these compounds are physically stable, since their ground electronic state has an energy that is smaller than the energy of the separated atoms. Molecules are considered as chemically stable if they can exist for an appreciable length of time even when colliding with each other at low temperatures. *OH*, *CH*, *CN*, etc., are thus not chemically stable, but they may be present in cometary atmospheres because of the low densities prevailing in such atmospheres, and the consequent almost complete absence of collisions. Similarly, *CH*, *CN* and CH^+ are observed in another "low temperature gas" of very low density—the interstellar gas.

The molecules giving rise to the observed bands cannot exist as such in the occluded state in the cometary solid particles, since they are not chemically stable. They result from the photo-dissociation of more complex, chemically stable parent molecules, which were present in the solid particles as occluded gases and were set free by the action of solar radiation. Part of the chemically stable molecules must be polyatomic compounds of hydrogen, carbon, nitrogen, oxygen, sulphur, and possibly some other elements.

It is perhaps not entirely legitimate to assume for the solid parts of the cometary nuclei (at least for their occluded gases) a chemical constitution similar to that of the meteorites found on the earth. Yet, as a working hypothesis, it may help to relate the gaseous constituents of cometary atmospheres to the chemical natures of the occluded gases in the various types of meteorites. The gas released from meteorites by breaking or heating them in vacuum may sometimes amount to sixty times the volume of the meteorite itself. The gases which have been found in meteorites are (61) CO_2, CO, CH_4, H_2, N_2, H_2S, SO_2, and there is little doubt that comets must also contain H_2O and NH_3.

For a specific solar excitation, *i.e.* at a specific heliocentric distance and for a specific radial velocity of the comet relative to the Sun, the intensity ratio of the scattered solar spectrum to that of the emission bands varies considerably from comet to comet, as do also to a certain extent the relative intensities of bands emitted by various molecules (62). Variations also occur among the occluded gases found in the different types of iron or stone meteorites (61), for example, the abundance ratio of CH_4 to CO (or CO_2) in stone meteorites differs considerably from the ratio in iron meteorites.

Each type of molecule has a definite range of extension in the head of the comet, corresponding to the mean free path before photo-dissociation or photo-ionization by solar radiation occurs. In order of increasing range of extension, we have the following sequence: CH, CH_2 and NH_2 (concentrated near the nucleus); OH; NH; CN and C_2. The ionized molecules CH^+, CO^+ and N_2^+ extend into the tail, but are observed in the head also, in the close neighbourhood of the nucleus. Our knowledge of the exact nature of the parent molecules and of the photo-dissociation and photo-ionization mechanisms is still very limited and vague. According to the Franck-Condon principle, a continuous absorption from the ground state, leading to the dissociation of the molecule, will be possible only if the nuclear distance r_e' in the upper electronic state is appreciably larger than that (r_e'') in the ground state. Cometary molecules may also be dissociated by absorption of solar light in a predissociation region of their spectrum. Accordingly, some predictions may be made with respect to the spectral regions of solar radiation that may dissociate specific molecules whose spectra have been analyzed in detail. In the case of C_2, for example, an excited electronic state exists about 6 volts above the ground state; this excited level has a nuclear distance, r_e', much larger than r_e''. Thus the absorption of solar radiation of wave-length shorter than about λ 2000, by C_2 molecules, will lead to their dissociation. The ionization energy of C_2 is about 12 volts; and hence, as indicated by K. Wurm (65), the ionization process is negligible for C_2, as compared with the efficiency of dissociation.

It may safely be assumed that the velocities of the various molecules in the comet's head originate mainly in the process of photo-dissociation of the parent molecules. When the gases occluded in the meteoritic nucleus are given off, they move away from the nucleus with velocities corresponding to their temperature in the nucleus. But the diatomic radicals resulting from the dissociation of these parent gases may move much more rapidly. As was shown by Wurm (65), this is illustrated by the extensions of CN and CO^+. The fact that CO^+ may be driven off in the tail, by light-pressure, at considerable distances from the nucleus, proves that the average lifetime of CO^+ in the field of solar radiation is long. Yet in the head itself, the CO^+ molecules are observed only very near the nucleus, or behind it in the direction of the tail. Since the masses of CN and CO^+ are not very different, their thermal motions cannot be very different. Thus we must conclude that their different velocities near the nucleus—giving rise to their different extensions in the head—result from the photo-dissociation mechanisms.

Our ideas about the relative abundances of the various molecules are still very vague. The observed intensities depend on the abundances, the oscillator strengths f, and the intensity of the exciting solar radiation. We have more or less reliable laboratory values for $f(OH)$ (66), $f(CN)$ (67), and $f(CH)$ (68); and theoretical values for $f(NH)$ and $f(C_2)$ (69). At present we can say only that the abundances of these five molecules in comets are all of the same order of magnitude. For example, it is true that the OH bands are very weak compared with those of CN, but $f(OH)$ is also very small compared with $f(CN)$, and the solar radiation is much weaker near λ 3090 (OH absorption) than near λ 3880 (CN absorption). No f values are available at present for CH^+, CO^+, N_2^+, OH^+, but we may assume that the f values for these ions are similar to those of the corresponding electronic transitions in the iso-electronic neutral molecules. The oscillator strengths are also unknown for CH_2 and NH_2.

Certain regions of a cometary head reveal CH molecules, both in the neutral and in

the ionized states. We do not know the relative oscillator strengths of CH and CH^+, and no photometric determination has been made of the relative intensities of the CH and CH^+ bands. Hence it is impossible to estimate the average ionization of the CH molecules (70).

The ionization potentials of CO, N_2 and CH, and the corresponding wave-lengths, are:

for CO,	$14{\cdot}1 \pm 0{\cdot}2\ v$,	or	λ 880;
for N_2,	$15{\cdot}51\ v$,	or	λ 800;
for CH,	$11{\cdot}13 \pm 0{\cdot}22\ v$,	or	λ 1110.

A direct photo-ionization of CO, N_2 and CH by solar radiation appears very improbable. If the Sun radiates like a black-body at $T \simeq 6000°\ K$, its continuum must be very weak around λ 1000. The situation is even worse because the Lyman absorption continuum, setting in at λ 912, must be extremely strong. Hence we should expect the amount of solar energy available for $\lambda < 880$ A. and $\lambda < 800$ A. to be extremely small. As for CH, its ionization limit falls about half-way between Lyman α (λ 1216) and Lyman β (λ 1026), which must be strong in the solar spectrum and have extensive wings. Excitation by impacts of solar electrons, such as we observe in the aurora borealis, may occasionally influence the ionization in comets, but is probably not the permanent source of ionization (71). Photo-dissociations of parent molecules into a positive and a negative ion are not excluded (71), but there is probably little we could say about it at present. Finally, ionization of CO, N_2 and CH in several steps, *via* intermediate (and possibly metastable) levels, may play a rôle.

Because of the low density and the small extension of the cometary regions common to CH and CH^+, there is practically no possibility of capture of electrons by CH^+ ions. In other words, once a CH molecule has been able to absorb photo-electrically a solar photon of wave-length shorter than λ 1110, there is practically no chance of an electron being recaptured. Hence, great care must be exercised when considering ionization in comets.

Absorption by molecules of CH, CN and CH^+ is found in another astronomical source, the interstellar gas. The only difference is that the C_2 bands which are strong in comets are absent in interstellar absorption. This may be explained theoretically (72). The similarity in constitution between cometary and interstellar gases is simply a consequence of the cosmic abundances of the elements, and of the characteristic physical properties of the molecules.

Actually, the problems of molecular formation are quite different in comets and in interstellar gas. In comets the atmosphere is generated by the liberation of gases occluded in the meteorites forming the nucleus; the observed molecules result from the photo-dissociation of these parent gases, accompanied or followed by ionization. The interstellar molecules result from the association of two atoms.

Much observational work remains to be done on the spectra of different parts of the comets; as was emphasized by Bobrovnikoff (73). Spectrograms should be taken of the next bright and active comet by placing the slit on such formations as jets, fans, edges of envelopes, etc.

No attempt will be made here to review or discuss the dynamical and photometric problems of comets; for these the reader may refer to recent papers by Bobrovnikoff (73).

The general conclusion of this review is clear: despite the recent progress many questions remain to be answered before we can hope to reach a clear understanding of the physical chemistry of comets. The help of the physicist is especially desirable for the investigation of the spectra of CN^+, C_2^+, NH^+, NH, etc., and for the determination of additional f values. A knowledge of the latter would make possible an estimation of the molecular abundances, and, as a result, a discussion of the photo-dissociation mechanisms in relation to heliocentric distance. Further investigations of the gases

occluded in meteorites of various types are desirable. Additional observations are also required in a number of fields, but especially spectroscopic observations in the red and near infra-red regions.

P. SWINGS

McDonald and Yerkes Observatories:
1943 *March.*

REFERENCES

(1) Swings, Elvey and Babcock, *Ap. J.*, 94, 320, 1941, and 95, 218, 1942; Popper and Swings, *ibid.*, 96, 157, 1942; Swings, *Lick Obs. Bull.*, 19, 131, 1941; Swings, *Lick Obs. Contrib.*, Series II, No. 3 (*Ap. J.*, 99, 270, 1942); Swings, *Pub. A.S.P.*, 54, 123, 1942; Swings, *Rev. Mod. Phys.*, 14, 190, 1942.
(2) For a general description, see P. Swings, *Lick Obs. Bull.*, 19, 131, 1941.
(3) Elvey, Swings and Babcock, *Ap. J.*, 95, 218, 1942.
(4) Popper and Swings, *Ap. J.*, 96, 157, 1942.
(5) Swings and Struve, *Pub. A.S.P.*, 55, in press, 1942.
(6) Private communication.
(7) A. McKellar, *Rev. Mod. Phys.*, 14, 179, 1942.
(8) *Ap. J.*, 89, 290, 1939.
(9) See, for example, *Pub. A.S.P.*, 52, 203, 1940.
(10) *Pub. A.S.P.*, 42, 119, 1930.
(11) This would be the isotopic band most easily detected in cometary spectra. No solar intensity maximum could explain the observed band satisfactorily. Of course, we cannot exclude the possibility that the observed feature may be due to a band as yet unknown.
(12) *Pub. A.S.P.*, 48, 323, 1936.
(13) *Lick Obs. Bull.*, 7, 8, 1912.
(14) *Ap. J.*, 34, 89, 1911.
(15) *Ap. J.*, 95, 270, 1942.
(16) *Ann. Obs. Astr. Phys., Paris*, 7, 58, 1926.
(17) Douglas and Herzberg, *Canadian Journal of Research*, 20, 71, 1942.
(18) The excitation of CO^+ molecules to the $B^2\Sigma$ level, by solar radiation, would require absorption through the first negative system $B^2\Sigma \leftarrow {}^2\Sigma$, around λ 2200. We should thus expect the Baldet-Johnson system to be much weaker than the comet-tail spectrum.
(19) A. E. Douglas and G. Herzberg, *Can. J. Research*, 20, 71, 1942.
(20) Private communication from Dr. Herzberg (from a plot of the frequency differences between corresponding band systems of ionized and neutral molecules against the atomic number).
(21) P. Swings, *Pub. A.S.P.*, 54, 123, 1942.
(22) *Rev. Mod. Phys.*, 14, 195, 1942.
(23) P. Ledoux, *P.A.*, 49, 513, 1941. (Summary of the symposium on interstellar lines at the Yerkes Observatory, on 1941 June 30.)
(24) *Ap. J.*, 96, 314, 1942.
(25) In a private letter Herzberg mentioned that, on account of the continuous photo-chemical decomposition of CH_4, a small stationary concentration of CH_2 may possibly be expected in the upper layers of the atmospheres of the major planets. Accordingly, Coudé-spectrograms of Jupiter were taken at McDonald Observatory, but they failed to reveal any trace of sharp absorption at the wave-lengths of the cometary CH_2 group. Herzberg has also been unsuccessful in his attempts to obtain the CH_2 bands either in absorption in the discharge in which they appear in emission, or in photo-chemically decomposed CH_2CO.
(26) The two bands λ 6053 and λ 6122 of the $\Delta v = -2$ sequence of C_2 have been included because they are comprised in complex groups; all the C_2 transitions from (0, 2) to (5, 7) were observed in Comet Cunningham.
(27) Eder, *Denkschr. Wien. Akad.*, 60, 1, 1893; Eder and Valenta, *Atlas Typischer Spektren, Vienna*, p. 10, 1911; Reis, *Zs. f. Phys. Chem.*, 76, 560, 1911; Fowler and Badami (hydrogen-nitrous oxide flame), *Proc. Roy. Soc.*, A, 133, 325, 1931; Gaydon (hydrogen-nitrous oxide and methane-nitrous oxide flames), *Proc. Roy. Soc.*, A, 181, 197, 1942.
(28) Rimmer, *Proc. Roy. Soc.*, A, 103, 696, 1923.
(29) *Nature*, 119, 235, 1927.
(30) *J. Chemical Physics*, 1, 500, 1933 (Table I).
(31) *Rev. Mod. Phys.*, 14, 195, 1942; *Ap. J.*, 96, 314, 1942.
(32) The data on the electronic structure of NH_2 are quoted from a private communication from Dr. R. S. Mulliken.

(33) Farkas and Harteck, *Zs. f. Phys. Chem.*, 27B, 111, 1934. We do not exclude the possibility that hydrazine molecules (N_2H_4) might play some rôle in the production of NH_2 or NH.
(34) *Pub. A.S.P.*, **38**, 177, 1926.
(35) *Lick Obs. Bull.*, **13**, 123, 1928.
(36) Wurm, *Zs. f. Ap.*, **13**, 179, 1936.
(37) *Nature*, **151**, 167, 1943.
(38) Duffieux and Grillet, *C.R. Paris*, **202**, 937, 1936; Jausseran, Grillet and Duffieux, *C.R. Paris*, **205**, 39, 1937.
(39) The "cathodic hypothesis," according to which the cometary gases are excited and ionized by electrons ejected from the Sun, has also been defended, especially by Deslandres, but it should now be abandoned, at least as far as excitation of the main bands (*CN*, *CH*, . . .) is concerned.
(40) *Ap. J.*, **34**, 342, 1911.
(41) *M.N.R.A.S.*, **89**, 178, 1928. See also Bobronvikoff, *Ap. J.*, **66**, 439, 1927.
(42) *Zs. f. Ap.*, **8**, 218, 1934 and **9**, 62, 1934.
(43) *Stockholm Observatoriums Annaler*, **13**, No. 11, 1941; *M.N.R.A.S.*, **99**, 630, 1939.
(44) S. Mrozowski, *Acta Physica Polonica*, **5**, 85, 1936; *Rev. Mod. Phys.*, **14**, 189, 1942.
(45) *Lick Obs. Bull.*, **19**, 131, 1941; *Pub. A.S.P.*, **54**, 123, 1942.
(46) *Rev. Mod. Phys.*, **14**, 179, 1942; *Ap. J.*, **97**, in press, 1943.
(47) Since collisional effects are unimportant in cometary atmospheres, the rotational and vibrational intensity distributions of the bands attributed to a specific molecule result only from the distributions in the rotational and vibrational levels of the excited electronic state. The isotopes may also influence the structure, but this has been considered in section 2.
(48) J. Dufay, *C.R.*, **206**, 1948, 1938; Swings, Elvey and Babcock, *Ap. J.*, **94**, 320, 1941.
(49) Adel, *Pub. A.S.P.*, **49**, 254, 1937; **50**, 247, 1938; Wurm, *Zs. f. Ap.*, **15**, 115, 1938; Wurm, *Ap. J.*, **89**, 312, 1939; Swings and Nicolet, *Ap. J.*, **88**, 173, 1938; McKellar, *Pub. A.S.P.*, **52**, 283, 1940; V. M. Slipher, *Bull. Lowell Obs.*, **2**, 67, 1914; **2**, 151, 1916.
(50) Minnaert, Mulders and Houtgast, Utrecht, 1940.
(51) Swings and Nicolet, *Ap. J.*, **88**, 173, 1938.
(52) This procedure should actually be used generally in astrophysics whenever fluorescence is excited by radiation which differs considerably from a black-body continuum, this being in fact the general case. The exciting radiation contains usually either absorption lines, bands or continua, or emission features, and these are shifted to a certain extent with respect to the excited gas, because of relative velocities.

Typical examples of astronomical fluorescence are: (*a*) Specific incomplete multiplets of *O*III and *N*III may be excited in nebulæ and similar objects, due to the coincidence of the resonance line of *He*II with an absorption line of *O*III, and another similar coincidence between *O*III and *N*III lines (Bowen's mechanism). The efficiency of this mechanism depends largely on the velocities of the layers emitting the *He*II spectrum, relative to the layers containing the O^{++} ions. Coincidences appearing more or less suddenly in the course of the evolution of a nova will enhance the *O*III and *N*III incomplete multiplets suddenly. (*b*) In shells surrounding stars of early type, peculiar selectivities are observed among the transitions in *He*I (variations in relative intensities of the triplets and singlets in emission), *N*III (presence of $3p^2P^0 - 3d^2D$ in emission, while $3s^3S - 3p^2P^0$ is present in absorption), *C*III (presence of $3p^1P^0 - 3d^1D$ in emission, while $3s^3S - 3p^3P^0$ is in absorption), *N*IV (same as *C*III), *Si*III (all the transitions whose lower levels are $4p^1P^0$ and $4p^3P^0$ appear in emission; conversely the lines whose upper levels are $4p^1P^0$ and $4p^3P^0$ are present in absorption only), *Si*II (absence of the usually strong doublet $3d^2D - 4f^2F^0$), *N*II, *C*II, *Fe*II, etc. . . . In the shells of lowest excitation (late Be and Ae stars), the Balmer lines themselves are excited by fluorescence. The underlying stellar radiation is considerably depleted beyond the Lyman limit, which reduces considerably the ionization of the hydrogen atoms in the shell, and consequently the recombination mechanism. As for the fluorescence excitation of the Balmer lines, its efficiency will be affected by the presence of Lyman absorption lines in the exciting radiation; this efficiency depends on the velocity and density distributions of the hydrogen atoms of the shell, and on the profile of the absorption lines of the exciting radiation; any variation in these factors will give rise to changes in intensity and profile of the Balmer emission lines. (*c*) In nebulæ excited by nuclei possessing absorption or emission lines, these features affect the excitations, ionizations, and recombinations to an observable extent. (*d*) The anomalous selectivities observed among certain emission lines in long period variables are probably due also to the presence of emission or absorption features, especially molecular bands, in the exciting radiation.

Evidently we may generalize, and instead of considering the excitation only, we may discuss the atomic and molecular ionization and the molecular dissociation mechanisms

in a field of diluted radiation which is not of the black-body type. A number of applications are then of interest: the spectra of novæ (for example, the appearance of molecular bands in these "too hot" atmospheres), the ionization of interstellar atoms, and the dissociation and ionization of interstellar molecules, the abnormal intensities of absorption lines in peculiar A stars (for example, the strength of the *Eu*II lines and the weakness of the *Ca*II lines in α^2 Canum Venaticorum), the general problem of the molecular abundances in late-type stars and the subdivision into *TiO*, *ZrO*, and carbon sequences of cool stars, etc. . . .

(53) *Zs. f. Ap.*, **15**, 115, 1938; *Ap. J.*, **89**, 312, 1939.
(54) *Ap. J.*, **97**, in press, 1943.
(55) McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942; J. Dufay, *Comptes Rendus*, **206**, 1948, 1938; Swings, Elvey and Babcock, *Ap. J.*, **94**, 320, 1941.
(56) Compared to the *P* branches, the Q_2 line seems very much weaker in Comets 1941 *d* and 1942 *a* than in Comet 1940 *c*; the reason is that, in the latter case, the emission measured at λ 3090 is a blend of Q_2 ($\frac{1}{2}$), Q_2 ($1\frac{1}{2}$) and Q_2 ($2\frac{1}{2}$), whereas the line measured in Comets 1941 *d* and 1942 *a* is mainly Q_2 ($\frac{1}{2}$).
(57) McKellar, *Pub. A.S.P.*, **52**, 283, 1940; Swings, Elvey and Babcock, *Ap. J.*, **94**, 338, 1941; Swings and Nicolet, *Ap. J.*, **88**, 173, 1938.
(58) Swings, Elvey and Babcock, *loc. cit.*
(59) Swings, *Lick Obs. Bull.*, **19**, 131, 1941 (Table 4, p. 135).
(60) McKellar, *Rev. Mod. Phys.*, **14**, 179, 1942.
(61) See, for example, G. P. Merrill, *Proc. Am. Phil. Soc.*, **65**, 119, 1926; also H. von Kluber, *Das Vorkommen der Chemischen Elemente im Kosmos*, Leipzig, 1931.
(62) Swings, *Rev. Mod. Phys.*, **14**, 190, 1942. For example, the relative intensities of the C_2 and *CH* bands compared with *CN* are definitely lower in Comet 1941 *c* than in Comet 1940 *c* at similar heliocentric distances, thus suggesting differences in chemical constitution of the heads of the two comets. Similar variations have been reported in the relative intensities of the *OH* and *NH* bands (Elvey, Swings and Babcock, *Ap. J.*, **95**, 218, 1941). See also the observations of F. Baldet (*Ann. Obs. Astr. Phys., Paris*, **7**, 1926). In a given comet the relative intensities of bands due to different molecules vary with heliocentric distance, but additional observational data of more quantitative character are required for the discussion of the physico-chemical mechanisms involved.
(63) The dissociation of C_2 molecules may also result from absorption of solar radiation in a predissociation region of the C_2 spectrum; see Herzberg, *Ap. J.*, **89**, 290, 1939.
(64) *Ap. J.*, **89**, 312, 1939.
(65) *Zs. f. Ap.*, **9**, 62, 1934.
(66) Oldenberg and Rieke, *J. Chem. Phys.*, **6**, 439, 1938.
(67) J. U. White, *ibid.*, **8**, 79, 1940.
(68) T. Dunham, Jr., *Pub. A.A.S.*, **10**, 123, 1941 (in collaboration with R. B. King).
(69) Mulliken and Mrs. C. Rieke, private communication (*OH*, *NH*, *CH*, *CN* and C_2, theoretical); Lyddane, Rogers and Roach, *Phys. Rev.*, **60**, 281, 1941 (*NH*, *CH* and C_2, theoretical).
(70) At any rate, the ionization of *CH* is much less advanced in comets than in interstellar space.
(71) P. Swings, *Pub. A.S.P.*, **54**, 123, 1942.
(72) *Lick Obs. Contr.*, Series II, No. 3, 1942; *Ap. J.*, **95**, 270, 1942.
(73) *Rev. Mod. Phys.*, **14**, 164, 1942; this paper contains also a complete bibliography on cometary spectra. For the problems related to cometary brightness, see Bobrovnikoff, *Perkins Obs. Pub.*, Nos. 15 (1941) and 16 (1942).

COMETS

Since the last report on Comets in *M.N.*, **102**, 107, 1942, four new comets and three expected periodic comets have been detected. The international situation is responsible for considerable delays in receiving information in some cases.

Comet Whipple (1942 *a*) was discovered by Whipple and also independently by Bernsconi on February 11. When the announcement of its discovery and an ephemeris were circulated in this country it was too far south for convenient observation.

Comet Oterma (1942 *b*) was discovered by Miss Oterma at Turku on February 12.

Comet Grigg-Skjellerup was found by Kanna Sekituti on May 11 very close to the position given by F. R. Cripps in *The Handbook of the British Astronomical Association*, 1942.

Comet Forbes (1929 ii) was found by van Biesbroeck on June 15. It was close to the position given by F. R. Cripps in *The Handbook of the British Astronomical Association*, 1942. Perihelion passage occurred half a day earlier than was assumed.

Elements of the Orbits of Comets

Comet	T(U.T.)	ω	Ω	i
		° ′ ″	° ′ ″	° ′ ″
Whipple	1942 Apr. 30·85622	223 25 58·9	340 07 25·7	79 25 55·3
Oterma (1)	Sept. 7·18	159 20	279 44	172 34
Grigg-Skjellerup	May 23·250	356 21 45·6	215 23 50·5	17 37 20·5
Forbes 1929 ii	Apr. 16·9025	259 37 14	25 35 46	4 37 25
Oterma (2)	Dec. 18·859	358 03 00	78 30 48	17 57 36
Wolf (1)	June 7·59	160 58 11	204 20 33	27 18 06
Whipple-Fedtke	1943 Feb. 6·74429	39 51 20·4	99 59 51·4	19 39 47·9

Comet Oterma (1942 *f*) was discovered by Miss Oterma at Turku on September 11. It was independently discovered by Tevzadze and has been identified with Comet Stephan (1867 i). Its magnitude at the time of discovery was 13.

Comet Wolf (1) was found by Baade at Mount Wilson on a plate taken on November 5. Its magnitude was 19·3. The ephemeris for this comet, by means of which it was found, is given in *The Handbook of the British Astronomical Association*, 1942. The computations were carried out by W. P. Henderson and H. Whichello.

Comet Whipple-Fedtke (1942 *g*) was independently discovered by Whipple and Fedtke on December 12. It became a naked-eye object early in 1943 and was extensively observed in this country.

SOLAR ACTIVITY

Sunspots.—Signs of approaching minimum within the next two or three years from 1942 are recognisable in several ways. The appearance in the near future of any small high-latitude sunspots of appropriate polarity will be of additional significance, preceding as they usually do the actual frequency minimum by about eighteen months.

The 1942 provisional sunspot number (Greenwich data alone) is 31 as compared with 47·5 for 1941, and 114 and 110 for the maximum years of the present cycle, 1937–38, these values being from the Zurich collective data. Monthly activity during 1942 showed a rise from January to April (sunspot number 65), followed by a rapid drop, after which only small fluctuations continued to the end of the year.

During the year, six groups reached or exceeded 500 millionths of the Sun's hemisphere. The largest and most interesting group from the joint solar and geophysical point of view was the naked-eye sunspot with central meridian passage on February 28·8: latitude 7° north and of maximum area 2000 millionths. The extensive chromospheric eruption that occurred on February 28 and the great magnetic storm which followed 19½ hours later are described in *The Observatory*, 64, 260, 1942. Another intense but short-lived eruption associated with the region of the big spot occurred on March 3 at a point of origin 42° west of the central meridian. An absorption streamer of $H\alpha$ was seen to cross the disk and project beyond the limb as a prominence (*Observatory*, 64, 261, 1942). The big sunspot itself returned to the central meridian on March 27·9, but there was neither a revival of intense chromospheric activity during this transit nor of terrestrial magnetic activity about March 28.

The third largest spot group of the year rose in area to 1000 millionths by November 2, on which day it crossed the central meridian in latitude 11° south.

Notes on sunspots and spectroscopic activity on the disk and in prominences at the limb are given in quarterly summaries in the *Journal B.A.A.*, compiled from the collective observations of members of that Association.

The number of magnetic storms recorded at Greenwich (Abinger) was nine as compared with sixteen in 1941. H. W. NEWTON

Observed during 1942

Comet	q	Period (years)	Equinox	Computers	Reference
Whipple	1·445091	...	1942·0	2	*H.C.O. Card* 624
Oterma (1)	4·2068	...	1942·0	1	*H.C.O. Card* 635
Grigg-Skjellerup	0·856083	4·91050	1950·0	3	*Handbook, B.A.A.*, 1942
Forbes 1929 ii	1·548684	6·42836	1950·0	3	*Handbook, B.A.A.*, 1942
Oterma (2)	1·600062	41·4	1942·0	2 and 6	*I.A.U. Circular*, 933
Wolf (1)	2·43735	8·28610	1950·0	4 and 5	*H.C.O. Card* 638, 639
Whipple-Fedtke	1·352438	Over 1000	1943·0	6, 7, 8 and 9	*Handbook, B.A.A.*, 1942 *B.A.A. Circular, etc.*, 236

Computers: 1, Miss Oterma; 2, Bobone; 3, Cripps; 4, Whichello; 5, Henderson; 6, Whipple; 7, Moller; 8, Kellaway; 9, Davidson.

The elements for Oterma (2) are from the computations of 6, and those for Whipple-Fedtke are from the computations of 8.

M. DAVIDSON

SOLAR ACTIVITY (CONTD.)

Prominences, 1941.—During the year 1941 there has been a considerable decrease in prominence activity as shown both by areas and numbers.

The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows:—

	Areas			*Numbers*		
	North	South	Total	North	South	Total
1941 January to June ...	2·49	1·58	4·07 sq. mins.	7·27	5·88	13·15
July to December ...	1·94	1·59	3·53 „	6·96	5·39	12·25

There has been a decrease of 24 per cent. in areas and 11 per cent. in numbers when compared with the figures for the previous year. Both the areas and numbers show a preponderance in the northern hemisphere. The distribution of areas in latitude shows maximum activity between 20° and 45° in the northern hemisphere and 15° and 30° in the southern. The distribution of numbers is nearly uniform from the equator to latitude 50° in both the hemispheres.

Twenty-six metallic prominences were observed during the year as against 33 in the previous year. Of these, 11 were in the northern hemisphere and 15 in the southern and all of them were observed from the equator to latitude 35°. Displacements of the Hα line in the chromosphere and in prominences observed during the year with the spectroscope numbered 54 as against 204 in 1940. Of these, 26 were towards red and the same number to violet and 2 both ways simultaneously.

Three hundred and sixty-four bright reversals of the *Hα* line on the Sun's disk in the neighbourhood of sunspots were observed with the spectroscope as against 744 in the previous year. The displacements observed in the neighbourhood of sunspots were 7 as against 44 during the previous year. Of these, 5 were towards the red and 2 towards red and violet simultaneously. D_3 was observed as a dark line on 276 occasions as against 676 in 1940.

The displacements observed in prominences with the spectrohelioscope were 65

as against 124 in the previous year. Of these 32 were in the northern hemisphere and 33 in the southern; 42 being on the east limb and 23 on the west. Displacements to the red numbered 37 and those to the violet were 28.

An eruptive prominence photographed on the west limb of the Sun on February 28 reached a maximum height of 10′ and had an area of nearly 11 square minutes.

The mean daily area of prominences projected on the disk as absorption markings (without foreshortening correction) was 3117 millionths of the Sun's visible hemisphere as against * 4480 in 1940, showing a decrease of 30 per cent. The distribution in latitude is nearly similar to that of prominences at the limb.

The largest absorption marking of the year, photographed on December 10, covered an area of about 4225 millionths of the Sun's visible hemisphere.

Prominences, 1942.—During the year 1942 there has been a further decrease in all forms of solar activity.

The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows:—

Areas

	North	South	Total
1942 January to June	1·79	1·88	3·67 sq. mins.
July to December	1·04	1·56	2·60 ,,

Numbers

	North	South	Total
1942 January to June	6·21	6·08	12·29
July to December	4·61	6·01	10·62

There has been a decrease of 16 per cent. in areas and 10 per cent. in numbers when compared with the figures for the previous year. Both the areas and numbers show a preponderance in the southern hemisphere. The distribution of areas in latitude shows maximum activity between 20° and 35° in both the hemispheres. The distribution of numbers is nearly uniform from equator to latitudes 40° and 50° in the northern and southern hemispheres respectively.

Twenty-six metallic prominences were observed during the year, being the same as in the previous year. Of these, 15 were in the northern hemisphere and 11 in the southern, and all of them were situated from equator to latitude 30°. Displacements of the *Hα* line in the chromosphere and in prominences observed during the year with the spectroscope numbered 84 as against 54 in 1941. Of these, 41 were towards the red, 39 towards violet and 4 both ways simultaneously.

295 bright reversals of the *Hα* line on the Sun's disk in the neighbourhood of sunspots were observed with the spectroscope, as against 364 in the previous year. The displacements observed in the neighbourhood of sunspots were 9 as against 7 during the previous year. Of these, 6 were towards the red and 3 towards red and violet simultaneously. D_3 was observed as a dark line on 185 occasions as against 276 in 1941.

The displacements observed in prominences with the spectrohelioscope were 210 as against 65 in the previous year. Of these, 104 were in the northern hemisphere and 106 in the southern, 107 being on the east limb and 103 on the west. Displacements to red numbered 119 and those to violet 91. The largest displacements observed were 5·5 A. to red and 5·5 A. to violet in an eruptive prominence on March 7.

An eruptive prominence photographed on May 1 on the east limb of the Sun reached a maximum height of nearly 8′·5.

The mean daily area of prominences projected on the disk as absorption markings

(without foreshortening correction *) was 2888 millionths of the Sun's visible hemisphere as against 3117 in 1941, showing a decrease of 7 per cent. The distribution of areas in latitude shows maximum activity between equator to latitude 20° in both hemispheres.

The one absorption marking worth noting was that photographed on February 2 which covered an area of about 5160 millionths of the Sun's visible hemisphere, stretching to a length of nearly 150° in both the hemispheres.

A. L. NARAYAN

DOUBLE STARS

New Pairs.—Barton (*A.J.*, **50,** 11) gives lists of double stars from the Sydney, Hyderabad and Toulouse Astrographic Catalogues and some visual discoveries. Kuiper (*Ap. J.*, **96,** 315) has notes on Proper Motion Stars, amongst which are 15 new visual binaries. Joy (*P.A.S.P.*, **54,** 33) finds the variable stars UZ Taur and RW Taur to be close visual double stars. Wirtanen (*P.A.S.P.*, **53,** 340) gives a new dMe double star.

Measures.—Finsen (*U.O.C.*, 104) publishes a list of measures with the 26½-inch refractor and Greenwich Astronomical Results for 1936 contains a list of observations with the 28-inch refractor. Doody and Burns (*Publ. Allegh. Obs.*, Vol. **8,** No. 6) give photographic observations and dynamical parallaxes of ADS 11635 and 11655.

Orbits:—

Star	Computer	*P*	*a*	*e*	Publication
		y	″		
ADS 3082	McLeod	180	0·57	0·42	*P.A.S.P.*, 53, 293
,, 3169	McLeod	225	1·05	0·224	*A.J.*, 49, 99
,, 8166	van den Bos	50·55	0·525	0·17	*U.O.C.*, 104
,, 15971 A, BC	Strand	400	3·403	0·60	*A.J.*, 49, 165
BC, B		25	0·080	0·0	
B 780	van den Bos	10·30	0·177	0·17	*U.O.C.*, 104
BD +45°2505	van Biesbroeck	13·4	0·74	0·75	*P.A.A.S.*, 10, 175
Mlb O 4 AB	Hirst	42·14	1·837	0·5738	*M.N.A.S., South Africa*, No. 25

Miscellaneous.—Van de Kamp (*A.J.*, **49,** 163) gives a note on the distant companion of Cincinnati 918.

Van de Kamp and Hoffleit (*P.A.A.S.*, **10,** 175) discuss the parallax and proper motion of the triple system 26 Draconis, Alden (*A.J.*, **49,** 115) the parallax and mass ratio of ψ Velorum. Barton (*P.A.S.P.*, **53,** 339) gives the proper motion in certain double stars.

Reuyl (*P.A.S.P.*, **53,** 336 and 338) discusses the orbital motion of Wolf 424 and HD 196982.

Kuiper (*P.A.S.P.*, **53,** 330) deals with the duplicity of Nova Herculis.

Sanford (*P.A.S.P.*, **53,** 291) gives the radial velocities of the secondary compounds of ADS 10937 and 14158.

Sanford and Karr (*Ap. J.*, **96,** 214) discuss the spectroscopic binaries Σ 1669 A and B.

W. H. VAN DEN BOS

* The foreshortening correction that was being applied to the areas of *Hα* absorption markings till 1940 was discontinued from 1941.

ADDRESS

Delivered by the President, Professor S. Chapman, on the Award of the Gold Medal to Dr. H. Spencer Jones, Astronomer Royal

At the previous Annual General Meetings of the Society since the outbreak of war, one of the chief peace-time events at such meetings has been omitted, as the Council had decided for the time being to discontinue the award of the Gold Medal. This year, I am very glad to say, the old custom is restored, and the Council have awarded the Gold Medal to the Astronomer Royal, Dr. Spencer Jones, for his determination of the solar parallax.

This great enterprise had its beginning at the Leiden meeting of the International Astronomical Union in 1928, when a Solar Parallax Commission was appointed with the Astronomer Royal as President. Its business was to prepare for full advantage to be taken of the favourable opposition of the minor planet Eros in 1930–31. This was an international enterprise, in which twenty-four observatories took effective part, in Russia, Germany, Belgium, Czecho-Slovakia, the United States of America, Italy, France, Spain, Japan, China, Argentina and the countries of the British Commonwealth. Valuable co-operation was given by Dr. Kopff in the formation of a catalogue of reference stars, and by Dr. Witt who supplied the ephemeris of the planet; but the planning and co-ordination of the work fell mainly upon our Medallist, and after the observations had been made he undertook the onerous task of assembling the material, and the highly skilled investigations needed to derive the parallax from it. Moerover, the circumstances of the opposition favoured the work of the southern observatories, and the Cape Observatory, of which he was then Director, made a great contribution to the observational material, so much so that the Cape plates contribute more weight to the final result than all the other observatories combined.

The full results are published in our *Memoirs*, **66**, Part II, 1941, and an abstract has been given in *Monthly Notices*, **101**, of the same year. The Society was favoured by our Medallist with clear and ample descriptions of his work at three of our meetings during that year, and therefore the Council decided not to ask me, in making the presentation of the Medal, to recount the grounds of the award in a full-length Address, which would inevitably have been much inferior to those which the Astronomer Royal has himself given us.

His main result is the value

$$8''{\cdot}790 \pm 0{\cdot}001$$

for the solar parallax, as compared with $8''{\cdot}807 \pm 0''{\cdot}0027$ and $8''{\cdot}806 \pm 0{\cdot}004$ obtained by Mr. Hinks from photographic and micrometer R.A.s of Eros at the previous opposition of 1900–1. The results from northern and from southern observatories, from right ascensions and from declinations, from photographic and from photovisual telescopes, and from four successive intervals during the opposition, all show excellent agreement, and so there is good reason to believe that every serious systematic error has been eliminated.

The observations also yield a value for the mass of the Moon, which has less than half the probable error of the previous determination.

The very substantial modification made by our Medallist's work in the accepted value of the solar parallax affects the estimated values of other astronomical and geophysical constants, and the Astronomer Royal has put our science still further under obligation to him by making a consolidated discussion and general adjustment of the values of all the inter-related constants; this is a subject on which his previous con-

tributions had already made him a leading authority. It must be specially gratifying to him, as it is to us, that the great enterprise he has now completed has enabled him to make substantial progress in mutually reconciling the fundamental astronomical constants, a problem to which so much of his earlier work was devoted.

Finally, it is a particular pleasure to me, as an old colleague of the Astronomer Royal, remembering the days when we were together as Chief Assistants at Greenwich, to have the privilege, in the name of the Society, of presenting this Medal. Dr. Spencer Jones, with this Medal, which your work has richly earned, go the best wishes of the Officers, Council and Fellows of the Society.

ADDRESS

Delivered by the President, Professor S. Chapman, on Magnetism in the Sun's Atmosphere

1. *Sunspot Studies : Visual and Telescopic Records.*—Telescopic observers of the Sun, followers of Galileo, amassed records that gradually led to a general view of the remarkable properties of sunspots. Schwabe recognized the 11-year cycle, afterwards traced far backwards in the long series of Chinese visual records of sunspots. Carrington and Spoerer established the passage of the sunspot zones from high latitudes to low, from one minimum sunspot epoch to the next; the discontinuous change of latitude at the minimum epoch marks each cycle as a unity. These and many other properties of sunspots have been portrayed by diagrams which embody the rich harvest of results from observations within the competence of a skilled and patient amateur astronomer using a small telescope.

2. *Solar Physics for the Public.*—Such discoveries could and should be made known to the public in vivid attractive ways. The pursuit of astronomy is made possible by the labours of our fellows in field, factory and distribution; they should share more fully in the interest, wonder and awe that we ourselves find in the marvels of the heavens. The coloured cinema film, with skilled commentary, could ensure this. By the co-operation of several solar observatories a fascinating film could be made, showing in one hour or less the solar panorama throughout one or more sunspot cycles. The children and citizens of to-day could experience afresh the delight of Galileo in discovering the rotation of the Sun, the appearance and disappearance of spots at the limbs, their birth or death on the disk; they could see the changing tilt of the Sun's axis as viewed from the Earth at different points of our annual orbit, and the passage of the sunspot zones towards the equator as the spots wax and wane in number throughout the 11-year cycle. The life-history of sunspot groups, and their association with flocculi and prominences, could be shown by separate "close-up" runs of film *; and other runs could show eclipse and coronal pictures, and the work of solar observers and observatories, past and present. The production of such a film seems to me to be an urgent and important duty for astronomers after the war, and merits the future attention of such bodies as the International Astronomical Union and the International Committee on Intellectual Co-operation.

3. *Sunspot Studies : the Magnetic Record.*—In 1908 the genius of Hale opened a brilliant new chapter in the history of sunspot studies; the rich harvest gained by simple telescopic observation has thus been greatly enhanced. Hale brought into the solar observatory the laboratory methods used by Zeeman to study the influence of a magnetic

* Such as those made by Lyot and McMath, some of which have been exhibited at pre-war meetings of the Society.

field on atoms emitting light. With great originality, skill and energy he developed new forms of solar observatory, tower telescopes with underground spectroscopic chambers; he also instituted laboratory studies to aid in interpreting his new solar observations. These ardent and successful labours up to 1924 are described by Hale and Nicholson in a notable volume.*

As Zeeman showed, the spectrum of the light from a radiating gas is modified by the presence of a magnetic field; single spectral lines are converted into two, three or more lines, and the light corresponding to these lines is polarized, in ways that depend on the direction of the field relative to the direction of emission (or viewing) of the light. By interposing suitable polarizing devices in the light-path of his spectroscope, Hale proved that certain hitherto unexplained multiple lines in sunspot spectra were due to the Zeeman effect. By determining the polarization of these lines, and their displacement from their normal positions, the intensity and direction of the field at the sunspot were measured. Such work became part of the regular daily programme of the Mount Wilson Observatory.

4. *The Magnetic Polarity of a Sunspot.*—Hale found that usually the magnetic field over any one sunspot was everywhere directed either into the spot or outwards from it †; that is to say, the sunspot is a magnetic pole, either positive or negative.

I may remind you that the north end or pole of a magnet, freely poised in the Earth's magnetic field, for example here in London, is called positive, and the south end negative.

Hale used the letters R and V, signifying red and violet, to indicate that a sunspot was a positive (R) or negative (V) pole; this was because the spectral line for a particular polarized component of the light from a *positive* sunspot pole was displaced towards the *red* end of the spectrum, and for a negative pole towards the violet end. Perhaps his choice of name ‡ was influenced by the old custom § of painting the north end of a magnet red and the south end blue. I shall follow Airy in referring to these magnetic poles as red or blue, and in many of my diagrams || will use these *colours* to indicate the magnetic polarity.

In any magnetic field, whether due to magnets or electric currents, the direction of the field at any point is defined as that of the force acting on a positive pole placed there; the force on a negative pole would be in the opposite direction.

Two poles repel or attract each other, according as their signs are like or unlike. Hence a positive pole is repelled when placed near the positive end of a magnet, and attracted when placed near the negative end, so that the field is directed *outwards* from the positive end and *towards* the negative end.

The connection between magnetic polarities and directions thus defined, and those determined on the Sun by the Zeeman effect, is of course made by laboratory studies of the Zeeman effect in known fields.

5. *The Magnetic Polarity of the Earth.*—As William Gilbert first announced, in A.D. 1600, the Earth itself is a great magnet. It has an Arctic magnetic pole, where a magnetic dip needle would point vertically downwards, and an Antarctic magnetic pole, where a dip needle points skywards. Thus the Arctic pole is negative or blue, and the Antarctic positive or red. Magnetic polarity is not confined to these two points; wherever the magnetic force is directed outwards—that is, upwards—the polarity is red. A line called the magnetic equator, along which a dip needle everywhere rests horizontal, divides the region of red polarity to the south from the region of blue polarity to the north.

* G. E. Hale and S. B. Nicholson, *Magnetic Observations of Sunspots*, 1917–1924; Carnegie Institution of Washington, 1938. This work will be quoted by its initials *M.O.S.*

† But in many sunspots the field is much more complex; see *M.O.S.*, pp. 40–44.

‡ If his definition had referred to the oppositely polarized light, his use of R and V would have been reversed.

§ G. B. Airy, *Treatise on Magnetism*, 1870, p. 5.

|| As shown on the screen, but not reproduced here.

6. *The Magnetic Polarity of the Sun.*—In 1913 Hale announced that the Sun also has a general magnetic field; as on the Earth, the red polarity extends over the southern hemisphere (*cf.* § 24).

7. *Magnetic Intensities.*—The intensity H at any point of a magnetic field is measured in terms of a unit called after Gauss *, because this great German astronomer and physicist was the first to measure the intensity in definite units; part of his method was to measure the time of oscillation of a magnet placed at the point. This time is proportional to $1/\sqrt{H}$, just as the time of oscillation of a simple pendulum, controlled by gravity, is proportional to $1/\sqrt{g}$.

The Earth's magnetic field is weak, though sufficient to be of great value to navigation. The intensity is about 2/3 gauss (or Γ) at the magnetic poles, and about half this along the magnetic equator.

Hale gave 50 Γ as the intensity of the Sun's general magnetic field at the poles, and 25 at the equator; this is about 75 times the intensity of the Earth's field.

Sunspot magnetic fields are far more intense; H may be 3000 Γ, or even more, at the centres of spots; on the whole, the greater the spot, the more intense is its magnetic field.

An intensity of 3000 Γ is decidedly strong, and is not greatly exceeded in large commercial electrical machines, where about 12,000 Γ is at present the maximum intensity in the air-gaps of the electromagnets. With great difficulty and expense much stronger fields can be produced in the laboratory; Kapitza † set up a field of 300,000 Γ for a hundredth of a second in a very small volume, 2 c.c., and his apparatus, if pushed to the limit, could produce 900,000 Γ for the same time in half this small volume. But the sunspot intensity of 3000 Γ may last for days and extend throughout many millions of cubic kilometres.

8. *Lines and Tubes of Magnetic Force.*—The direction of a magnetic field can be made visible by iron filings, which show the *lines of magnetic force*; and we can imagine narrow *tubes* of magnetic force, likewise everywhere directed along the field. Let A denote the area of cross-section of such a tube, and H the magnetic intensity, at any point P; in free space the product AH is the same all along the tube, just as, in a water-pipe of variable section A, the product of A into the water-speed v is the same all along; thus H or v is greater where the tube is narrower, and less where it is wider. The product Av for the water-pipe gives the rate of flow or delivery of water; by analogy AH is called the magnetic flux along the tube of magnetic force.

9. *Magnetic Flux and the Strength of a Magnetic Pole.*—The magnetic intensity H at distance r from an isolated magnetic pole is proportional to $1/r^2$; if $H = m/r^2$, m is called the strength of the pole. The magnetic lines and tubes are radial from (or to) the pole. The total cross-section of all the tubes, at the distance r, is $4\pi r^2$, so that the total magnetic flux AH from the pole is $4\pi r^2 H$ or $4\pi m$; this is true also when other poles or an additional field distorts the tubes leaving the pole.

On the Earth the magnetic tubes rise from the southern magnetic hemisphere and descend into the northern one. The total flux from one to the other is $2\pi a^2 H_0$, where a denotes the Earth's radius and H_0 the equatorial surface magnetic intensity ($\frac{1}{3}$ Γ); its numerical value is about 82 million Γ km.^{2}. The large area makes the flux great though the field is weak, whereas the flux for the intense field leaving a pole-piece in a large electric dynamo (§ 7) is only about 1/10 Γ km.^{2}.

The corresponding flux passing from the south to the north hemisphere of the Sun (§ 7) is 76 million million Γ km.^{2}, about a million times that of the Earth.

10. *The Magnetic Flux and Pole Strength of a Sunspot.*—To calculate the magnetic flux from or into a typical large sunspot, we must know how H and its inclination θ to the vertical are distributed over the spot. Nicholson has determined θ at different

* The name oersted is also used.

† *Proc. Roy. Soc.*, A, 115, 658, 1927.

radii r from the spot-centre, by measurements both on the disk or on the limb, with reasonably accordant results (fig. 1), which correspond approximately to

$$\theta = (\pi/2)(r/b), \tag{1}$$

where b denotes the spot radius to the outer edge of the penumbra.

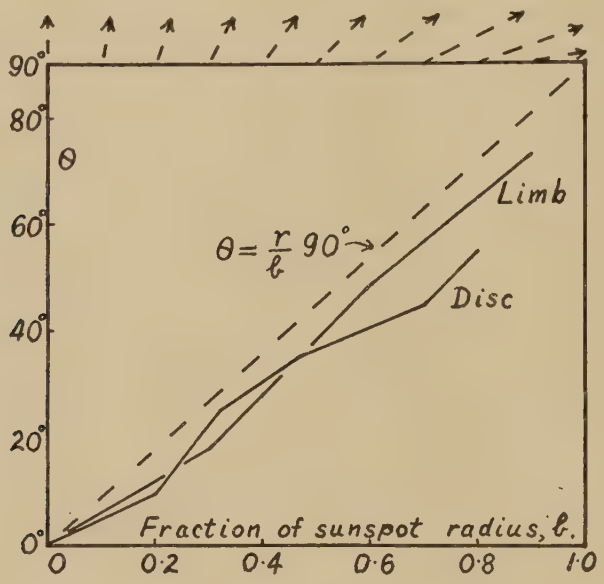


FIG. 1.

So far as I know the Mount Wilson publications do not give the variation of H with r, but J. W. Broxon *, apparently on information supplied by Nicholson, has stated that

$$H/H_0 = 1 - r^2/b^2, \tag{2}$$

where H_0 is the intensity at the centre. Thus the vertical component of the intensity, $H \cos\theta$, is given by

$$H \cos\theta = H_0(1 - r^2/b^2) \cos(\pi r/2b). \tag{3}$$

The average value of this over the spot area is

$$(96H_0/\pi^2)(1 - 2/\pi - \pi/12) \tag{4}$$

or 0·315 H_0 or, sufficiently accurately, $H_0/3$. Thus the flux from or into the spot is $\frac{1}{3}\pi b^2 H_0$. Fig. 2 shows a graph of H/H_0 according to (2), and another (curve *a*) of $H \cos\theta/H_0$ according to (3) (*cf.* § 17).

Broxon refers to the great unipolar sunspot M.W. 6618 of 1939 September 21 to October 1 †, 14° S., for which H_0 was 3600 Γ; its maximum area was 1939 millionths ‡ of the Sun's visible disk, so that $b = 28{,}000$ km. Thus its magnetic flux was about 4 million million Γ km.² (or 4×10^{22} Γ cm.²), roughly 1/20 of the general flux of either solar hemisphere, and immensely greater than the Earth's flux.

The equivalent pole strength of either hemisphere of the Earth or Sun is obtained by dividing their flux by 4π.§

* *Phys. Rev.*, **62**, 521, 1942. † *P.A.S.P.*, **51**, 362, 1939.

‡ See also *Observatory*, **62**, 307, 1939.

§ The appropriate divisor in the case of a sunspot seems to me to be only 2π, but the difference, a factor of 2, is of little importance in the present state of our knowledge of solar physics.

11. *Magnetic Dipole Moments.*—Though it is often convenient to think of isolated magnetic poles, one feature that most distinguishes magnetism from electricity is that magnetized bodies always have two opposite poles, or two distributions of opposite polarity, of the same aggregate strength: thus the net pole strength is zero.

The simplest conception of a magnet is that of two equal unlike point poles, of strengths $\pm m$, separated by a distance d. The product $md(=M)$ is called the dipole moment of the magnet; it is a vector, directed from the negative to the positive pole.

When magnetism is distributed throughout a volume, the field at a distance approximates to that of such a dipole, whose poles $\pm m$ have strengths equal to the total positive and negative distributions of magnetism, and are situated at the centres of these two distributions.

For a uniformly magnetized sphere of radius a and equatorial surface magnetic intensity H_0, the equivalent dipole, situated at the centre of the sphere, has the moment H_0a^3, along the direction of magnetization. For the Earth this dipole moment is 81 thousand million Γ km.^{3} (or $8{\cdot}1 \times 10^{10}$); for the Sun it is 8·4 million million million Γ km.^{3} (or $8{\cdot}4 \times 10^{18}$). The presence of the additional factor a in the dipole moment as compared with the flux (§ 9) naturally increases the preponderance of the Sun over the Earth in this respect.

12. *Sunspot Dipole Moments.*—Hale found that most sunspot groups, at some stage in their life-history, show bipolarity—that is to say, they include two spots, or two regions or groups of spots, of opposite magnetic polarity, one "red" and the other "blue" (§ 4). At other stages, however, there is often only one spot, of like polarity over all its area—this is called a unipolar spot.

A typical spot group begins as two small spots, or two groups of spots, of opposite polarity, nearly in the same latitude, and 3° or 4° apart in longitude. The two principal spots * grow rapidly and separate in longitude to a distance of 10° or more; the rear spot attains its maximum area in 3 or 4 days; the leader attains a larger maximum area in 7, 8 or 9 days; many smaller spots develop within the group, mostly near the two main ones. The dipole moment of the group is greatest when the spots are largest and furthest apart.

Consider a notable case, that of the great bipolar group M.W. 6725, 8° S., consisting of two great spots each of radius 20,000 km., about 14° apart, together with many smaller spots between †; for this group $H_0 = 3900\,\Gamma$; considering only the two large spots, the dipole moment ‡ is 5×10^{16} Γ km.^{3}—600,000 times as great as the Earth's dipole moment, and about 1/170 of that of the Sun. The sunspot dipole moment is of course horizontal, and nearly parallel to the Sun's equator, though the leading spot is generally somewhat nearer to the equator than is the follower. At the equator the dipole axis is along the equator, and according to W. Brunner § its inclination to the equator increases with latitude to about 16° at 30° latitude.

13. *The Laws of Sunspot Magnetic Polarity.*—The dipole directions of the sunspot groups throughout any solar cycle, from one sunspot minimum to the next, show considerable though not complete regularity. Almost all those on one side of the equator

* R. S. Richardson, *P.A.S.P.*, 51, 230, 1939, reports observations implying that a sunspot is in pure radiative equilibrium at 4300° K; they give no indication of upflow of adiabatically cooling gas.

† See W. T. Whitney, *P.A.S.P.*, 52, 34, 1940, showing a picture of this group on 1940 January 5; also *ibid.*, pp. 42, 148.

‡ Earlier calculations of the dipole moment of a large sunspot pair have been made by K. O. Kiepenheuer (*Zs. f. Ap.*, 15, 53, 1938) and by J. W. Broxon (*loc. cit.*, § 10); their values were respectively 10^{15} or more, and $5{\cdot}2 \times 10^{16}$. These two writers, for the purpose of calculations on solar prominences and cosmic rays respectively, treated the dipole moment as being vertical instead of horizontal. (Broxon's calculation referred to the unipolar spot M.W. 6618, § 10.) See also H. Alfvén, *Arkiv. f. Mat., Astr. o. Fys.*, 27, No. 25, 11, 1941.

§ *Ast. Mitt. Zurich*, 124, 67, 1930.

point forwards, and those on the other side rearwards. But at each sunspot minimum these directions are reversed in each hemisphere. Thus the complete cycle of sunspot change includes two 11-year periods. At sunspot minimum either hemisphere may contain sunspot groups belonging to the old and new 11-year cycles, with opposite dipole directions.*

These grand discoveries greatly extend our conceptions of the solar cycle and of sunspot phenomena, and enhance the already rich synthesis afforded by the sunspot studies of the pre-magnetic period.

14. *The Non-Spot Flux.*—A typical spot group, after attaining its maximum in about a week, declines much more slowly, during weeks or even months. The rear spot breaks up into several small ones, which shrink and disappear; after two or three weeks from the birth of the group, the leader survives alone as a unipolar spot, gradually shrinking but seldom breaking up.

The flux from a unipolar spot must return into the Sun, but it does so in an unspotted region, where it may be called a *non-spot* flux. It must exist also, in less degree, while a sunspot group consists of a stream of spots; those of opposite polarity generally lie on opposite sides of a line near the centre of the stream (*M.O.S.*, p. 35), and the flux for the front part of the group exceeds that for the rear part, which has a smaller aggregate area and a smaller average magnetic intensity.

15. *The Location of the Non-Spot Flux: the Evidence of the bright Flocculi.*—It is of great interest to determine where this non-spot flux enters or leaves the Sun. A hint as to its location is given by the occasional intermittent reappearance of the rear spot after it has first vanished (*M.O.S.*, pp. 37, 48). A still stronger suggestion is made by the bright calcium flocculi † commonly associated with sunspot groups; they herald the coming of the group a day or two before the visible birth, and they cover the whole region of the group even after the rear spot has vanished. Thus they often indicate that a unipolar spot is the leader of a partly vanished bipolar group, even if the earlier history of the group has not been observed. In the closing days of the group, as the surviving leader spot shrinks, so do the flocculi, especially those to the rear; at the end they are symmetrically placed over the dying leader (*M.O.S.*, p. 31).

Except at this last stage, the facts suggest that the non-spot flux may be located around the rear spots, or in the region formerly occupied by them. Consequently Hale and Nicholson searched for local magnetic fields in the rear flocculated region; they used an ingenious device which alternately switched light of opposite polarization in rapid succession through the spectroscope, so that a slight Zeeman effect due to a weak magnetic field revealed itself by a quivering of the spectral lines. This successfully disclosed regions of non-spot flux, or *invisible sunspots*, as Hale called them. Hale and Nicholson remark (*M.O.S.*, p. 38) that: "If a persistent search for invisible spots were made with the best of seeing and a larger solar image and higher dispersion than we employ, it is probable that greater numbers of them would be found, especially in the flocculi following large unipolar spots."

Such special studies on the non-spot flux seem very desirable, to complete the magnetic balance-sheet for a typical spot group throughout its history, and especially during the last phase when the flocculi show no rearward extension.‡ It would also be of great interest to know whether there is any upper limit of intensity for the non-spot flux.

* These relations were illustrated on the screen by Hale's diagrams, but with the bipolar spots shown in colour, and by Maunder's butterfly diagram, with alternate "wings" coloured (as a whole) red and blue, to show the change of polarity of the leading spots. More accurately, the actual lines representing the spots in Maunder's diagram should be coloured red or blue according to the polarity of single unipolar spots, or of the leading spots of bipolar pairs.

† Also hydrogen flocculi; see *M.O.S.*, p. 38.

‡ It is of particular interest in connection with the dipole moment to locate the non-spot flux at this stage.

The magnetic flux across the Sun's surface originally centres round the two new-born spots, and its distribution over the leader spot seems to remain nearly circular; but to the rear the distribution becomes elongated. Whereas over the leading spot *H* may rise to a single central maximum, over the disintegrating rear part of the group the small spots probably indicate "peaks" in an irregular ridge-distribution of magnetic intensity. It would be of interest to determine, if possible, the variation of the inclination of *H* in this region. Such studies seem to promise valuable light on the changing distribution of the hydrodynamical causes that are probably responsible for the appearance and magnetism of sunspots.

16. *Solar Hydrodynamics.*—It can hardly be doubted that the two parts of a bipolar sunspot group arise from a common cause and are closely related to each other; but the nature of the cause and the relationship is still unknown.

Hale supposed the two poles to be the ends of a sub-surface vortex loop. V. Bjerknes * devised a much more far-reaching sketch of solar hydrodynamics, to explain not only the individual spot-pairs, but also their latitude-progression and the double solar cycle.

He pictured in each hemisphere two great sub-surface vortices, with opposed rotations, which encircle the Sun's axis and are carried to and fro in the spot-belt of latitude, by a circulating current in the outer part of the Sun; in each 11-year cycle one vortex-ring is uppermost, and is transported from the upper sunspot latitude to the equator, where it descends for the return passage at a deeper level. A bipolar sunspot group marks a break where this upper vortex, for some reason, rises locally to the surface.

Unsöld † suggests an additional circulation in higher latitudes, carrying two further ring-vortices, in order to explain the occurrence and latitude-progression of polar faculæ and prominences, not accompanied by visible spots. But as to the spots associated with the Bjerknes circulation, Unsöld prefers the view that they correspond to loop-vortices, as Hale proposed, which are detached pieces from one of Bjerknes' ring-vortices.

As yet all this is hypothesis, with little quantitative basis; but the remarkable collective properties of sunspots offer a fascinating difficult field of study to one versed in hydrodynamics and vortex theory.

The granulations of the Sun's surface appear to be ever-changing cellular vortices in the thin outer layer where the transition takes place from great to slight ionization of hydrogen; it has been suggested that the radial fibres of sunspot penumbræ are also instability vortices, in a layer subject to radial shear. But the sunspot vortices and their movements are hydrodynamic phenomena on a far grander scale, in a sphere of gas in shearing motion due to the non-uniformity of the Sun's angular velocity (which varies with the latitude and the depth) and also to the slow equatorward motion of the spot zones.

Being unable to show you an actual picture of a sunspot vortex, I show instead four (American) pictures ‡ of terrestrial tornadoes, the most impressive vortices visible to us in Nature. These differ from sunspot vortices in origin, in type, and most of all in their scale, which is utterly insignificant compared with sunspots; but the energy associated with them, so great judged by terrestrial standards, will suggest what vast kinetic energy may be linked with sunspots.

17. *The Sunspot Magnet.*—A sunspot, on a superficial view, is a magnetic island in a non-magnetic region: but its magnetic flux can be mapped out by imaginary tubes of force, which form closed rings; each tube that issues from the Sun returns thither again, and completes its ring below the surface, to the point of issue. It is a natural supposition that its sub-surface course is along the supposed hydrodynamic vortex, but at present we do not know whether or not this is a simple loop; if it is, a sunspot pair and its vortex resemble a horseshoe magnet with its ends in the Sun's surface.

* *Ap. J.*, 64, 93, 1926. † *Physik der Sternatmosphären*, p. 388.

‡ Kindly lent from the collection of the Royal Meteorological Society.

The magnetism must be due to electric currents: an actual iron magnet could not exist in the Sun. But electromagnetic theory shows that any steady distribution of electric currents is magnetically equivalent to a certain distribution of magnetized matter, and *vice versa*. For example, a cylindrical iron bar uniformly magnetized along its length has the same distribution of magnetic flux as a uniform flow of current of suitable intensity round the curved surface of the cylinder, as in an ordinary solenoid. For the moment, therefore, let us consider the magnet model of the sunspot pair; in form and size, it is likely to coincide more or less with the unknown vortex beneath the surface.

The great French mathematician Poisson gave a convenient method of calculating the magnetic field of any distribution of magnetized matter, not necessarily uniform. In the case of a uniformly magnetized straight bar magnet his method shows that the field outside is the same as if the bar were replaced by two uniform layers of magnetic matter, one over each end, positive at the positive end and negative at the other. The same is true also if the bar instead of being straight is semicircular, so that its end can simulate a bipolar spot; or if it is partly straight and partly circular, so that it might simulate Bjerknes' broken vortex curving up to the surface, except that we here suppose the cross-section is the same all along, not funnelling out at the surface, as in the diagrams of the solar vortices.

If we place side by side a number of straight magnets, equal in length but magnetized to different intensities, and fitting together to form one solid bar magnet, its outside field will be the same as that of positive and negative distributions of magnetic matter over its two ends, but now the surface density, instead of being uniform, is proportional to the magnetization of the different bars; the same is true also for a semicircular magnet in which the intensity of magnetization is not uniform across any normal section.

If the two ends, whether of the straight or the semicircular magnet, are sufficiently far apart, we can calculate the magnetic field near each as if the other were not there. Suppose that the surface density σ over the end depends only on the distance r from the centre of the end; then the magnetic intensity H, and its inclination θ, will likewise depend only on r. I have calculated θ for various relationships between σ and r, in order to find what distribution of σ would agree approximately with Nicholson's measurements of θ for a sunspot (§ 10, (1)). The details may be omitted here; I give only the results for the assumed variation of surface density,

$$\sigma=(H_0/2\pi)(1-r^2/b^2)^2. \tag{1}$$

This corresponds to the expression (see curve b of fig. 2)

$$H\cos\theta=H_0(1-r^2/b^2)^2, \tag{2}$$

instead of § 10 (3), for the distribution of the normal component of the intensity; the numerical values of the two expressions are very nearly equal, as fig. 2 shows. I find that Nicholson's observed variation of θ with r is consistent, within the limits of observational error, with the distribution of σ given by (1), but the latter does not agree with § 10 (2); I hope to describe these calculations in a later Note. This calculation must be modified, however, if the sunspot electromagnet funnels out near the surface (§ 21).

18. *The Sunspot Electromagnet.*—The *electromagnet* corresponding to the model sunspot *magnet* just considered is a volume distribution of electric currents filling the imagined "body" of the model magnet, the flow being round the axis, with an electric current density j given by

$$j=\frac{d\sigma}{dr}=\frac{1}{2\pi}\frac{dH}{dr}\cos\theta=-2(H_0/\pi b)(r/b)(1-r^2/b^2).$$

This is zero at the axis ($r=0$) and boundary ($r=b$) of the distribution, and elsewhere its distribution is shown in fig. 3; the maximum j is $0{\cdot}77\ H_0/\pi b$, at $r=b/\sqrt{3}=0{\cdot}577b$.

The total flow of current across a radial half-plane through the axis of the magnet is $H_0/2\pi$ electromagnetic units (or 10 $H_0/2\pi$ amperes) per cm. length along the axis, or 10^6 $H_0/2\pi$ amperes per km. length. For example, if $H_0 = 3000\ \Gamma$, this current flow is

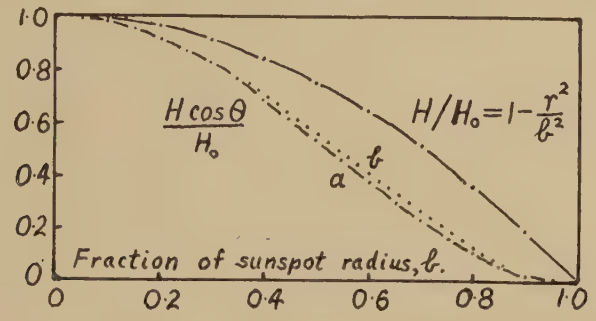


FIG. 2.

Average vertical intensity over spot
$= \frac{1}{3} H_0$

480 million amperes per km. along the axis (for example, per km. of depth below the spot). This is about two thousand times the total electric current flow which in the Earth's ionosphere produces the daily variation of the compass.

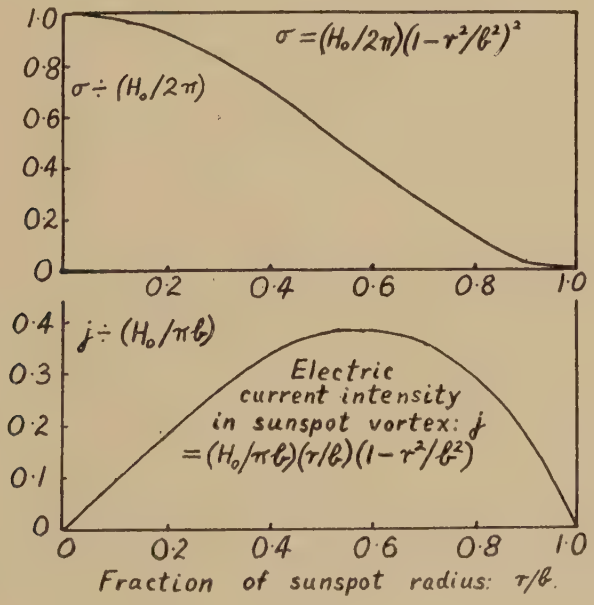


FIG. 3.

The current flow is anticlockwise, as seen from the Earth, round the axis of a sunspot of red polarity, and clockwise round a "blue" spot.

19. *The Electromagnetic Pressure Distribution in a Sunspot.*—If two bar (or horseshoe) magnets are placed side by side, with their like poles together, they repel one another. A bundle of such magnets, making up a solid magnet of similar form, could be held

together only by outside pressure or by tension in strings or bands around them; for this reason an ordinary solid magnet is in lateral tension, being held together by its own cohesion.

In the sunspot electromagnet, the magnetic field at any radius r, acting on the current flowing round the axis, produces a similar effect, namely, an outward force jH or $d(H^2/8\pi)/dr$ per unit volume; this causes a total rise of pressure, from the axis to the sides of the electromagnet, of amount $H_0^2/8\pi$ dynes per sq. cm. If $H_0 = 3000\ \Gamma$, this pressure difference is 360,000 dynes per sq. cm., or about one-third of an atmosphere.

This, however, may be only a part, perhaps only a small part, of the rise of pressure outwards from the spot centre, the remainder being due to vortex motion.

20. *The Magnetic Attraction between the Spots of a Bipolar Group.*—Whereas each spot tends to expand under the magnetic repulsion of its parts, in a bipolar group the two spots of opposite polarity attract each other. This attraction can be estimated roughly, when the spots are 10° or more apart, by treating each as a point magnetic pole; considering two spots similar to the one referred to in § 10, of pole strength $2 \times 10^{22}/\pi\ \Gamma\text{cm.}^2$, at a mutual distance of 125,000 km. (about 10°), the mutual attraction in dynes is $4 \times 10^{24}/(1{\cdot}25\pi)^2 \times 10^{20}$, or roughly $2{\cdot}5 \times 10^{23}$; this is about equal to 250 million million tons weight (on the Earth). For two such spots only 3° apart, the attraction would be about 10 times as great.

During the growth of a spot group, the spots move apart against this strong magnetic attraction. Doubtless their motion is determined by still more powerful hydrodynamic forces.

Two spot groups in low latitudes on opposite sides of the equator, and in the same longitude, will likewise strongly attract one another. It would be of interest to study the motions of sunspot groups taking these and other magnetic attractions and repulsions into account, in order to examine statistically whether there is any evidence of the magnetic forces having slight systematic effects on the motion.

The Sun's general magnetic field will also exert a force on each spot, tending to push the "red" one northwards and the "blue" one southwards, and thus tilt the axis of the spot-pair, like a compass needle, towards the meridian; the force on each spot, of the pole strength $2 \times 10^{12}/\pi\Gamma$ km.^{2}, is from 150 to 200 million million tons weight, depending on the spot latitude. When the leading spot in the northern hemisphere is blue and in the southern red, as in the 11-year cycles whose maxima occurred in 1907 and 1928, these forces tend to tilt the spot pairs in the observed directions; but in the alternate cycles the tendency is opposite. Here again the magnetic forces must be secondary, the tilt being controlled by hydrodynamic forces. But it may be worth while to examine whether, as one might expect, the average tilt, say in latitudes $\pm 20°$ or $\pm 25°$, is greater in the first-mentioned set of 11-year cycles than in the alternate cycles.*

21. *Magnetic Energy and Self-Induction in the Sunspot Electromagnet.*—A field of intensity H has magnetic energy of amount $H^2/8\pi$ ergs per c.c. At a spot centre where $H = 3000\ \Gamma$, this is $3{\cdot}6 \times 10^5$; compare this with the energy radiated per second per sq. cm. of the Sun's surface, which is 6×10^{10} ergs, or at the centre of a sunspot about $1{\cdot}2 \times 10^{10}$; the radiation per second from a spot centre is as much as the magnetic energy within a column $\frac{1}{3}$ km. deep.

The magnetic energy of sunspots is distributed in the atmosphere above them, and in the sub-surface electromagnet or solenoid. Except near the sunspot ends of the solenoid, the lines of force will run nearly parallel to its axis; let H_1 denote the magnetic intensity along the axis of the solenoid, beneath the surface, where its radius is b_1; suppose that H, at radius r, is distributed according to the formula $H = H_1(1 - r^2/b_1^2)^2$,

* An examination of the valuable tables in W. Brunner's paper, *Ast. Mitt.*, 124, 1930, suggests that any such difference between the two sets of cycles must be very small.

like the *vertical* magnetic intensity over the sunspot. Then the total magnetic energy per cm. length of the solenoid is $H_1^2 b_1^2/40$. If the solenoid everywhere has the same cross-section (which is perhaps unlikely), $b_1 = b$ and, allowing for leakage of flux round the sides near the sunspot ends of the solenoid, $H_1 = 2H_0$; in this case, taking $H_0 = 3000\ \Gamma$, $b = 30{,}000$ km., the energy per cm. length of the solenoid is 10^{25} ergs. In any case, $H_1 b_1^2 = 2H_0 b_1^2$ because the flux must be the same all along the solenoid (approximately half leaks out sideways near the end, and so does not issue from the spot); hence $H_1/H_0 = 2(b/b_1)^2$, and the magnetic energy per cm. length is $2H_1 H_0 b^2/40$; this is $H_1/2H_0$ or $(b/b_1)^2$ times the value calculated above.

This energy has an important influence on the rate at which the solenoidal currents and their magnetic field can grow or decline. If the causes maintaining them were suddenly to cease, the currents would die away, owing to the electric resistance of the solar gas in which they flow; during this decay the magnetic energy would supply the energy dissipated by the currents into heat. The greater the energy, and the less the resistance, the slower is the decay, just as, in an ordinary circuit of resistance R and self-induction L (which determines the magnetic energy $\frac{1}{2}Li^2$ for a current i), the current decays proportionately to $e^{-Rt/L}$, that is, in a time of the order L/R.

In the sunspot solenoid the rate of conversion of energy into heat, owing to the resistance to the currents, is $j^2\tau$ per unit volume, where j denotes the current-intensity and τ the resistivity of the gas. Integrated over the cross-section, the total loss of energy per cm. length of the solenoid, if τ is uniform * over the section, is $\tau H_1^2/12\pi$ (independent of b_1). The magnetic energy per cm. length, $H_1^2 b_1^2/40$, could supply this energy for a time of the order $(12\pi/40)b_1^2/\tau$ or roughly b_1^2/τ. This gives the time of free decay of the current-system, and also the time of growth under constant electromotive forces suddenly set up. For a given value of τ, the time is proportional to b_1^2—so that a big spot may be expected to grow and decay more slowly than a small one.

On the vortex-loop theory of a sunspot pair, the vortex and its electric current-system and magnetic field completely die away, the time of decay being usually from 12 to 35 days (or about 10^6 to 3×10^6 seconds); the relation $b_1^2/\tau = 10^6$ or 3×10^6 may give us some indication of the value of b_1 for the solenoid beneath the Sun's surface. This requires the estimation of τ, a problem too technical to be discussed in this Address; but I should guess that its value, at a depth of a few hundred km., is between 10^8 and 10^{10}. This implies that b_1 lies between 10^7 and about $1{\cdot}7 \times 10^8$ cm., or from 100 to 1700 km. —much less than the radius of a big sunspot. This favours the idea that the sunspot vortex funnels out near the surface. It also implies that H_1 may be much greater than 3000 Γ (from 200,000 to 500 million Γ), with a correspondingly greater electromagnetic difference of pressure between the axis and sides of the solenoid.

22. *The Magnetic Topography of the Sun.*—We are on firmer ground in considering sunspot magnetic fields *above* the Sun's surface. Near each spot of a well-separated pair the field can be calculated (as in § 17) as if the other spot were absent; but at distances large compared with the spot-radii the field may be calculated as if each spot were a point pole. This is illustrated by fig. 4, which Dr. Dasgupta has kindly prepared for me; on the right is shown half the diagram of the lines of force from a point pole $-m$ at P to a point pole $-m$ at P' on the left; if the diagram were rotated about the line joining the two poles, these lines of force would generate surfaces; the lines are chosen so that one-eighth of the flux from the pole m (that is, $m/2\pi$) "flows" between successive surfaces; on the left the full lines correspond in the same way to the pole-strengths $-m$ and m spread uniformly along two lines centred at P' and P, lying along the line $P'P$, and each of length $P'P/6$; the broken lines on the left correspond to the pole-strength $-m$ centred at $\pm'$, but spread uniformly over a length $P'P/2$, the pole-strength m at P being distributed over a length $P'P/6$ as before. These dotted lines illustrate the case of two spots of unequal size. Except close to the spots the three sets of lines

* Probably τ will not be uniform, and an average value over the section must be used.

of force are very similar.* They would be still more similar if the pole-strength m, instead of being spread uniformly, had been concentrated towards the line-centres.

The lines of force due to two point poles lie in planes through the two poles, and this will be nearly true for two sunspot poles. If the Sun's axis were perpendicular to the line from the Earth to the Sun, and if the two sunspot poles had exactly the same latitudes, the lines of force would be seen edgewise, as limited straight radii, when the spot-group centre was on the Sun's limb. Owing to the tilt of the Sun's axis, and the difference in latitude between the two spots (which may be 2° or more in latitude 30°), the lines of force would actually appear at the limb as loops. It would be of interest

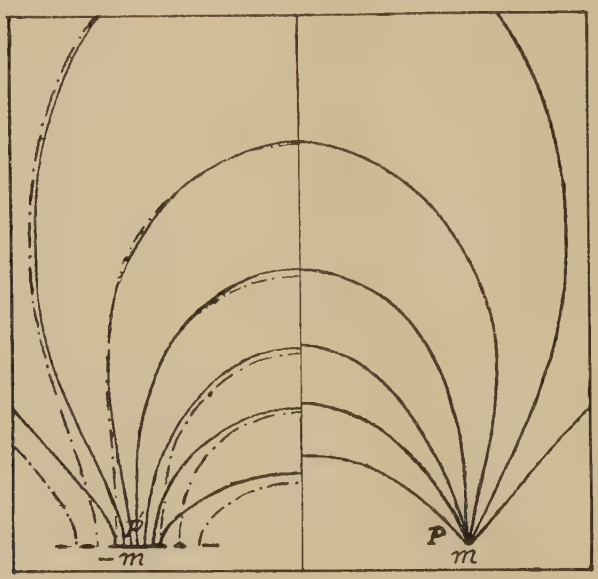


Fig. 4.

to calculate the forms of such loops for comparison with the forms of clusters of prominence loops.

The forms and directions of the sunspot lines of magnetic force are less simple when more than one sunspot group is on the disk; some lines of force will connect opposite sunspot poles of different groups. If one bipolar group follows another in the same latitude, the row of four spots will be successively opposite in sign, and lines of force will link successive spots in three series of loops. If two sunspot groups occur in different latitudes in the *same* hemisphere, with the leader of one group on or near the meridian of the follower of the other group, the lines of force connecting them will run in the north-south direction; this will happen also when the leaders (and followers) of sunspot groups on *opposite* sides of the equator are in nearly the same longitude—one set of lines of force will connect the two leaders, and another will join the two rear spots.

It would be of interest to construct models illustrating the magnetic topography of the Sun by means of wires, showing the varied forms and distributions of the lines of force, and also the distribution of magnetic intensity, corresponding to the various relative positions and strengths of sunspot groups seen on the Sun.

23. *Prominence Arches and Magnetic Lines of Force.*—The fascinating films of solar

* In one respect the diagram is misleading: from a line-distribution of magnetic matter the lines of force leave at right angles, whereas in general over a surface distribution they leave the surface obliquely.

prominences shown in this room by American * and French † colleagues strongly suggested the guidance of prominence matter, in many cases, along a curved line—guidance like that afforded by a smooth wire to a bead running on it. This guidance may be due to the magnetic field. It is certainly true that ionized gas can move directly or obliquely *across* a magnetic field, but if it starts moving *along* the field, any tendency to diverge from the magnetic lines calls into play forces that tend to prevent or reduce the deviation, whether this is due to the curvature of the magnetic lines, or to forces on the gas acting obliquely to these lines. The restoring forces are proportional *inter alia* to H^2, the square of the magnetic intensity; hence they are the same whether the motion of the gas is along or opposite to the direction of H, and also they are weakest at the top of an arch joining two spots, and increase towards each end of the arch.

In 1919 two great prominence arches ‡ were seen at the east limb, one on May 29 and the other on July 15. They appeared to lie nearly in meridian planes, and each crossed the equator; in both cases the top of the arch was "blown" away from the Sun. The second of these arches § ranged in latitude from $+11°$ to $-18°$; its north end was near the great unipolar spot M.W. 1500; Gr. 8971 ($H = 2800\ \Gamma$), in longitude 126°·6 and latitude 7°·5 N., and at its south end there was another great spot, mainly unipolar, M.W. 1502; Gr. 8973 ($H = 3100\ \Gamma$), in nearly the same longitude, 114°·3, and in latitude 13°·7 S.‖ In this case there must have been lines of magnetic force linking the two great spots across the equator, and running nearly north and south; before the arch broke up its form may have coincided with some of these lines.

On May 29 the great prominence arch extended over about 45° of latitude; in the north it ended in the great unipolar spot M.W. 1452; Gr. 8917 ($H = 3000\ \Gamma$), in longitude 10°·5 and latitude 7°·2 N.; but there is no record of a southern spot near the same meridian at that time. The northern spot was of red polarity, and lines of force proceeding southwards from it would run counter to the Sun's general field.

24. *The Combination of the Sun's general Magnetic Field with Sunspot Fields.*—If prominence matter flows along lines of magnetic force, these lines must correspond to the combination of sunspot fields and the general field. Unfortunately there is still some doubt even as to the *existence* of the general field, and more as to its distribution and properties.¶ The Mount Wilson work perhaps affords *prima facie* grounds for believing in its existence and in the stated polarity **, and sets a valuable upper limit to its intensity; but the finer points of the published results, namely the radial limitation, and the obliquity and rotation of the magnetic axis, are more doubtful.††

The sunspot fields, in the main, run east and west, across the north-south direction of the general field; the latter will materially influence the sunspot fields only in their outlying parts where the intensity becomes comparable with $50\ \Gamma$, the maximum intensity of the general field. For a great bipolar group such as was considered in § 12,

* R. R. McMath and his co-workers at the McMath-Hulbert Observatory.

† B. Lyot.

‡ E. Pettit, *Ap. J.*, 50, 206, 1919.

§ E. Pettit, *Pub. Yerkes Obs.*, 3, 1925; see fig. 9, p. 224. It would be advantageous if all drawings of prominences at the Sun's limb indicated, as does Dr. Pettit's fig. 7 for the prominence of 1919 May 29, the solar latitudes concerned; it would also be convenient if the limb (E. and W.) were indicated.

‖ There was also a weaker spot, M.W. 1501; Gr. 8972 ($H = 1100\ \Gamma$), in nearly the same longitude, namely 123°·8, and in latitude 7°·4 S.; this was the rear spot of a bipolar group, and therefore its polarity must have been opposite to that of the much greater and more southerly unipolar spot.

¶ Early references and summaries on this subject are G. E. Hale, *Ap. J.*, 38, 27, 1913; F. H. Seares, *Observatory*, 43, 310, 1920. More recent references are G. E. Hale, *Nature*, 136, 703, 1935; Mount Wilson *Annual Reports*, 33, 138; 34, 171; 35, 173; V. Ferraro, *Observatory*, 61, 241, 1938.

** But see *M.O.S.*, p. 54, where it is stated that "apparently" the polarity does not change with the sunspot cycle.

†† H. D. Babcock, *P.A.S.P.*, 53, 237, 1941, reports new observing devices that promise well for improved measurement of the general field.

this intensity of 50 Γ will be reached, for example midway between the two spots, at a height of about 100,000 km. At this level the Sun's field (if not radially limited) would be 2/3 as intense as at the surface in the same latitude; thus it would appreciably alter the direction of the sunspot field there.

Where sunspot lines of force run nearly north and south, the general field will alter the magnetic intensity and inclination rather than the azimuth.

There seems to me to be some hope of inferring whether the general field exists, and, if so, what is its intensity and distribution, by a study of the forms of prominences. But the fulfilment or failure of this hope will depend on our first gaining a satisfactory understanding of the causes of prominence motion.

25. *Electrical Fields associated with Changing Sunspot Fields.*—Finally I may refer briefly to electrical effects due to the changing magnetic field of sunspots. In an atmosphere like that of the Sun, containing numerous ions and electrons, no appreciable accumulation of charge of one sign can occur, because it would produce a strong electrostatic field that would dissipate the charge. But electric fields may arise not only from distribution of electric charge; they result also from changing magnetic fields.

A magnetic field has two sets of vector lines associated with it: the lines of magnetic force already considered, and the lines of the vector potential **A**; for a dipole, for example, the **A** lines are circles about the dipole axis. When the magnetic field is changing, it produces an electric field $-\dot{\mathbf{A}}/c$ (e.s.u., c denoting the velocity of light). Changes in sunspot fields, especially the more irregular and rapid changes, may produce important local electric fields, impelling electric currents in adjacent ionized gas. These currents will tend to shield the interior of the gas from the magnetic changes. The magnetic field will exert mechanical forces on the electric currents, and these forces are likely to have an important influence on prominence motions.*

Such electromagnetic effects in the Sun's atmosphere offer a rich field for study, comparable in interest and importance to the hydrodynamic studies called for to explain the remarkable collective properties of sunspots. Of these two fields of work we may truly say they are white unto harvest, but alas the labourers are few.

* K. O. Kiepenheuer, *Zs. f. Ap.*, 15, 53, 1938; also 10, 260, 1935.

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